SPECIAL REPORT

THE COMING ERA OF SPACE EXPLORATION p. 12

OCTOBER 2022

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Dunes in the solar system — like this field inside Victoria Crater on Mars — hold secrets to planetary evolution and atmospheres. NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA/CORNELL/OHIO STATE UNIVERSITY

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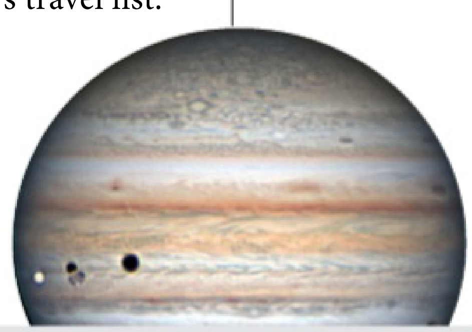

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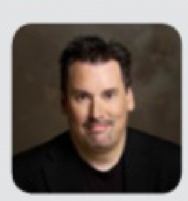

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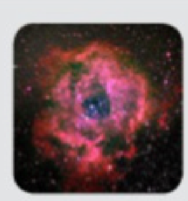

Picture of the Day
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FROM THE EDITOR

A new era in astronomy

The first five released images from the James Webb Space Telescope, including this shot of galaxy cluster SMACS 0723, have the astronomy world electrified.
NASA, ESA, CSA, AND STSCI

In mid-July 2022, the astronomy world was turned on its ear by a first release of five images from the James Webb Space Telescope (JWST). Launched on Christmas Day 2021, the telescope represents a giant leap in sophistication over its predecessors. Webb's primary mirror is a 6.5-meter (21 feet) diameter reflector composed of 18 hexagonal segments, each coated in gold. As expected, its first images confirmed that we are now in a new era of astronomy, one that we hope will deliver countless discoveries.

The night before the full release, President Joe Biden and Vice President Kamala Harris released the first image, the deepest shot of the universe ever taken to date. Depicting the galaxy cluster SMACS 0723 in the southern constellation Volans, the image reveals incredible gravitational lensing of distant protogalaxies. The result is the sharpest view of the most distant galaxies we have yet seen, objects that accreted a few hundred million years after the Big Bang.

Rather than a pretty picture, the spectrum of a nearby gas giant exoplanet, WASP-96 b, revealed the most incredible news of that day — the detection of water vapor in the planet's atmosphere. Some 1,150 light-years away lies a world that may well be suitable atmospherically for living beings.

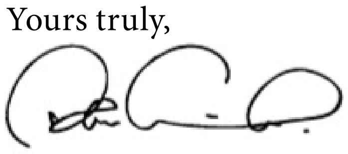
A longtime favorite of backyard astronomers, galaxy group Stephan's Quintet, was another feature. Tidal interactions between the galaxies were suddenly crystal clear, as if putting on a pair of glasses from our previous best view.

The Southern Ring Nebula gave us the most distinctive look to date at a planetary nebula, foreshadowing our Sun's future. Six or 7 billion years from now, our solar system will dissipate away in a cloud of cosmic soot that reveals the Southern Ring.

And there was also a stunning portion of a nebula in Carina — not the Carina Nebula itself, but NGC 3324, a glorious star-forming region. The image was just jaw dropping, and left us wanting more.

Welcome to a new era of astronomy. The deluge of images and discoveries will now keep us busy, and excited, for years to come.

Yours truly,



David J. Eicher
Editor

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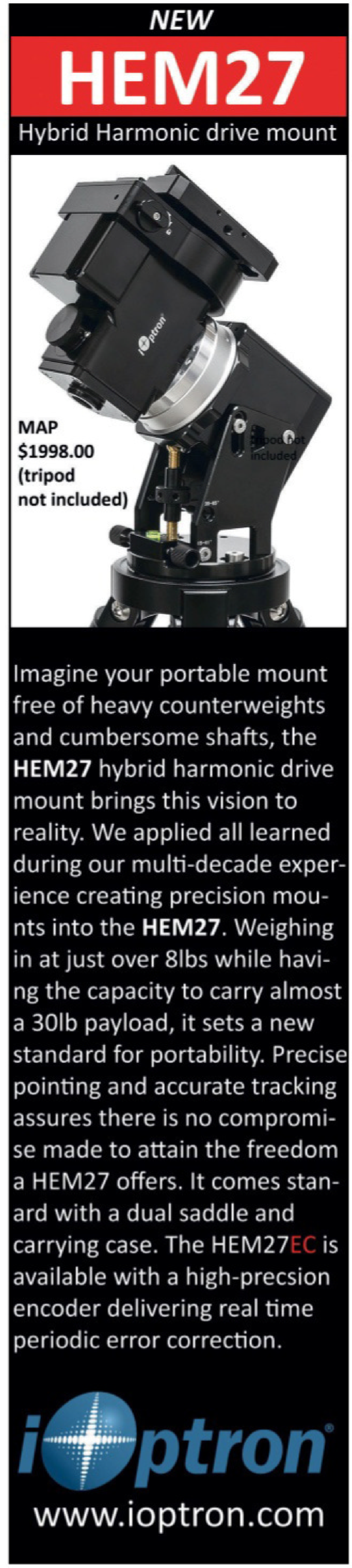

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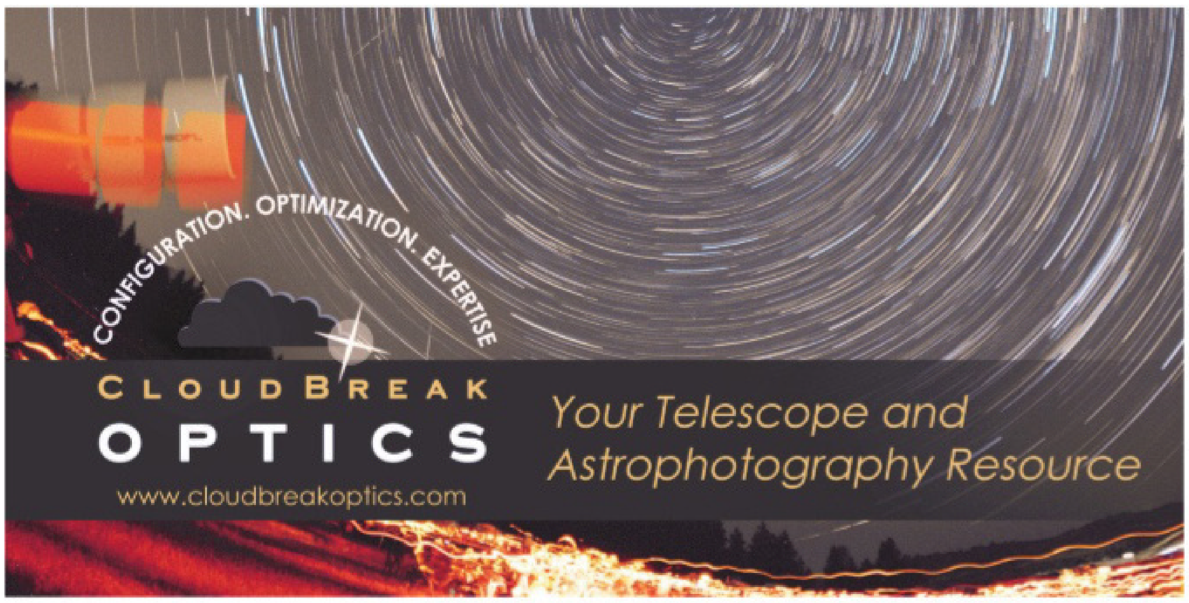

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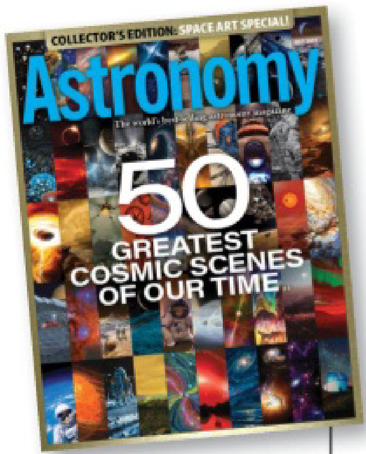


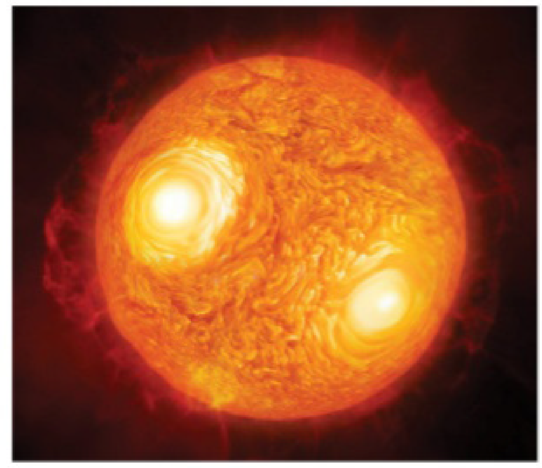
Humanity in Science

As I slid your July issue from the mailbox, my first reaction was, "Art? That's not what I'm subscribing to *Astronomy* for!" However, it took only a moment's reflection to replace that thought with one of appreciation and agreement. It is our dreaming and reaching out for what we cannot yet touch that has pioneered our voyages to the planets and beyond, and our technology will always trail in the wake of those dreams. As I turned the first pages, I was deeply touched by Marilynn Flynn's "Shamshu Sojourn," depicting two astronauts holding hands as they view the jovian vista before them. If we do not bring our full humanity with us as our science takes us to the stars, then what's the point? **—John Cimbaro,** Lake Worth, FL

We welcome your comments at Astronomy Letters, P.O. Box 1612, Waukesha, WI 53187; or email to **letters@astronomy.com**. *Please include your name, city, state, and country. Letters may be edited for space and clarity.*

Live Long and Prosper

The *Star Trek* article by Michael Bakich was fantastic. I always wondered if the shows used real names of stars and planets. I liked how he blended the technical information with the uses in the sci-fi series. The star maps were great, too. And I just have to get those postage stamps. **—Paulette Jones,** Edgewood, MD



Antares is located in the constellation Scorpius, and it is one of many real stars mentioned in *Star Trek*. ESO/M. KORNMESSER

Highly Illogical

In Michael Bakich's article, "An Observer's Guide to *Star Trek*" (May 2022), he failed to mention an obvious observable: the star Antares, in the constellation Scorpius. Lieutenant Uhura performed "Beyond Antares" in two episodes of *The Original Series*: "The Conscience of the King" and "The Changeling." **—Rebecca Unger,** Joshua Tree, CA

Erratum

In Bob Berman's June column, a word was unintentionally dropped during editing. The second-to-last paragraph should have read "Beyond that, according to ideas from Stephen Hawking, John Wheeler, and other theoretical physicists, a past that is *not* set in stone can't be entirely ruled out."

SNAPSHOT

THE DEEPEST INFRARED VIEW EVER

ON JULY 11, President Joe Biden presented the first science image from the James Webb Space Telescope (JWST) in a press briefing. It is the deepest infrared shot ever taken, showing a galaxy cluster called SMACS 0723. Some 4.6 billion light-years distant, this cluster is acting as a gravitational lens, revealing (and distorting) galaxies behind it. Due to their extreme distances, these ancient background galaxies are heavily redshifted, appearing like bright orange-red tadpoles in a cosmic whirlpool.

Whereas the Hubble Space Telescope required weeks to take such deep-field shots, JWST needed only 12.5 hours to grab this view of SMACS 0723. And it's more than just a pretty picture: Researchers were even able to determine the basic chemical composition of a 13.1-billion-year-old galaxy (below) in the background, the farthest ever characterized. —CHRISTOPHER COKINOS

NASA, ESA, CSA, STSCI

JWST STUNS WITH FIRST SCIENCE

After more than two decades and $10 billion — and surviving a 2011 Congressional effort to kill the project — the James Webb Space Telescope (JWST) has finally delivered its first batch of science images. And, simply put, wow.

The first image, of galaxy cluster and gravitational lens SMACS 0723, was unveiled July 11 at a briefing with U.S. President Joe Biden and Vice President Kamala Harris. The rest — images of three targets and an exoplanetary atmosphere spectrum — were released July 12 during an hour-long broadcast on NASA TV featuring an elated science team.

The photos were selected by a team of representatives from NASA, the Space Telescope Science Institute in Baltimore (which operates JWST), the Canadian Space Agency, and the European Space Agency. Their subjects represent a range of the types of targets that JWST will investigate throughout its mission: a galaxy cluster, two nebulae, a tight group of interacting galaxies, and a strange exoplanet in our Milky Way.

JWST is the most powerful space telescope ever built, with a 6.5-meter

IMAGES NASA's next-generation observatory is now operational.

NASA, ESA, CSA, STSCI

COSMIC CLIFFS

The Carina Nebula is a stellar nursery forming massive stars some 7,600 light-years away. JWST's image of a portion of the nebula captures a brown bank of gas and dust with the appearance of a ridge, silhouetted against the starry sky behind it. Nicknamed the Cosmic Cliffs, the image reveals hundreds of stars never before seen by human eyes. That's because JWST is built to detect infrared light, which penetrates gas and dust. The unparalleled view shows gas congealing to create stars and jets of energy sculpting the surrounding nebula; these jets aid star formation in some places and slow it in others. —C.C.

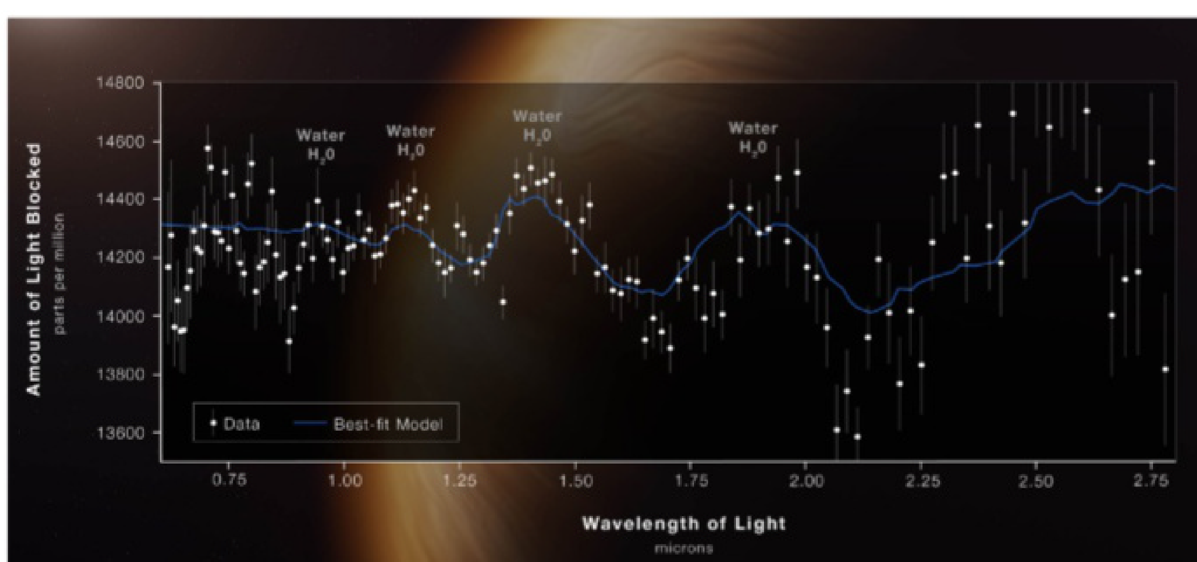
mirror made of 18 gold-plated hexagons, a tennis-court-sized sunshield, and four high-tech instruments working in visible and near- to mid-infrared wavelengths. It orbits the Sun at the L2 Lagrange point, where the combination of gravitational forces from Earth and the Sun keep it in a relatively stable position.

Since its launch from French Guiana Dec. 25, 2021, JWST has had no major issues. One event, however, has triggered much analysis: In May, a mirror segment was struck by a micrometeoroid. Such impacts are inevitable, but this one was larger than expected. The performance hit from the single impact is measurable, but small — still well within the design specifications. Only time will tell whether JWST was simply unlucky to suffer such a hit early in its life or if it is more susceptible to impacts than predicted.

Nevertheless, JWST has performed flawlessly. That's very good news: Unlike Hubble, which resides in low Earth orbit, JWST is too far away for servicing. Mission engineers say the observatory has enough fuel to last 20 years — but if it breaks down, that's it.

In other words, a great deal is riding on this dream instrument. Researchers around the world plan to use JWST to study everything from the evolution of the early universe to potentially habitable exoplanets. This first set of observations, which were released to the astronomical community in raw form July 13, are the beginning of science returns that promise to revolutionize many aspects of astronomy for decades to come.

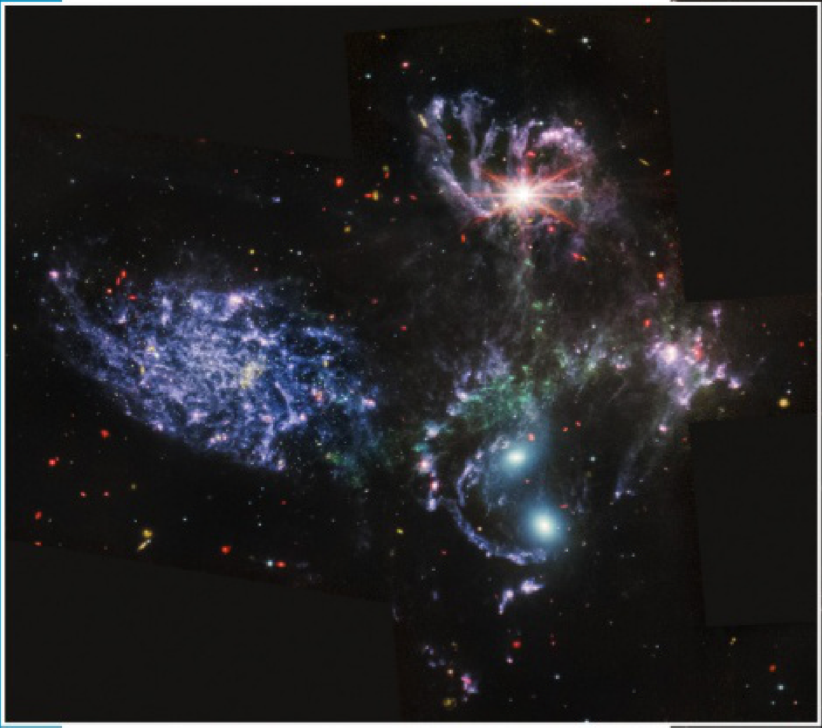
"Now we've demonstrated that this telescope can do what we set out to do, and even better in some cases," said Amber Straughn, JWST's deputy project scientist for communications, at a press conference after the images were revealed. "Astronomers are ready for this data. We've been waiting a long time." —C.C.



NASA, ESA, CSA, STSCI

Steam world

The first of JWST's exoplanetary targets was the gas giant WASP-96 b, which orbits a star roughly 1,150 light-years away in the constellation Phoenix. JWST observed the planet as it crossed in front of its host star, as it does every 3.5 days. By analyzing the starlight that streamed through the planet's atmosphere, scientists uncovered preliminary evidence of water vapor, suggesting that WASP-96 b features clouds and hazes. —C.C.



NASA, ESA, CSA, STSCI (2)

Celestial dance

AT ONE-FIFTH THE MOON'S DIAMETER, this near-infrared image (right) of Stephan's Quintet occupies the widest view yet released from JWST. The leftmost galaxy (NGC 7320) resides only 40 million light-years away, while the other four (from top: NGC 7319, NGC 7318B, NGC 7318A, NGC 7317) are some 290 million light-years distant.

JWST caught astounding detail at near-infrared wavelengths: Individual stars clearly appear in NGC 7320. In the mid-infrared (above), shock waves ripple through the galaxies as NGC 7318B bulldozes through the cluster. And at the bright heart of NGC 7319, heated material falling into a supermassive black hole at the center shines some 40 billion times brighter than the Sun. The data reveal new information about the temperatures and motions of this glowing gas that will help astrophysicists better understand what happens around black holes. – C.C.

DYING STAR'S FINAL ACT

JWST took two images of the Southern Ring Nebula, this one in mid-infrared and another in near-infrared light (page 66). This shockingly detailed view of the object — which looks a bit like an amoeba or an algae bloom — reveals, for the first time, the dim star responsible for the planetary nebula. At the center lies a white dwarf and a brighter companion, their tight orbit stirring the cloud of gas and dust, producing the strange patterns. By using JWST to monitor the interplay of starlight, gas, and dust in this system, scientists will gain a much better sense of the dynamics of dying stars, as well as the planetary nebulae they produce. – C.C.

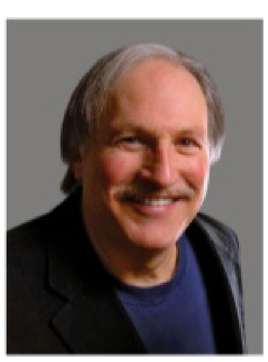
NASA, ESA, CSA, STSCI

Seeking shade

Let's settle the debate on which solar filter to choose.

ABOVE: Recent research confirms that viewing the partial phases of a solar eclipse through welders' glass in shade 12 or darker is safe — but which provides the best experience? MROTCHUA/DREAMSTIME

CENTER: You'll also need a filter for viewing *all* phases of an annular eclipse, as the Moon doesn't cover the entire solar disk. HAJIME NAGAHATA (CC BY 2.0)



BY BOB BERMAN
Bob's recent book, Earth-Shattering *(Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.*

It's now only 1½ years until the next U.S. total solar eclipse. On April 8, 2024, the Moon's shadow will head north out of Mexico to throw parts of 15 U.S. states and a few Canadian provinces into full totality. It'll be 20 years before we get another one.

Solar totality is almost surely the greatest natural spectacle the eye can behold. It lasts only a few minutes, but for an additional two hours, the event's partial phases offer themselves for observers who have eye protection.

Solar totality is almost surely the greatest natural spectacle the eye can behold.

For my first totality, at Virginia Beach in 1970, I bought black-and-white film, which I fully exposed and then developed. Two layers of that created a safe filter. But no more — film, if you even remember what that is, no longer reliably contains the silver emulsion that's vital for blocking harmful rays.

When I started leading eclipse tours in the '80s, I always provided shade No. 12 welders' filters. Then, when the internet arose and some websites claimed only the darker shade 14 was safe, I'd bring a bunch of those along, too. We'll get to aesthetics in a minute, but first let's look at the all-important issue of safety.

At https://eclipse2017.nasa.gov/safety, NASA says "The only [welders' filters] that are safe for direct viewing of the Sun with your eyes are those of Shade 12 or higher." The American Astronomical Society (AAS) used identical phrasing before that same totality.

Those wanting technical information can turn to a recent study by researchers at the School of Optometry and Vision Science in Waterloo, Ontario, and Sydney, as well as Rick Fienberg of the AAS. Published last September in *The Astronomical Journal*, its evaluations of dozens of solar filters "support the use of welding filters between the shades of 12 and 16."

So, you can safely count on shades 12, 13, and 14. (You wouldn't want a 15 or 16 because the image is too dark.) And yet you can still find websites warning to only use a shade No. 14. A few also advise against looking at the Sun for more than 15 seconds. One site cautions that even through a dark No. 14 filter, you should only observe the Sun when it's totally eclipsed.

Eclipse-savvy readers will laugh at that one, since if you actually followed that last bit of advice, you'd see complete blackness and miss everything. Moreover, *The Astronomical Journal* paper notes that the government standard all eclipse filters (including the brightest safe welders' filter, shade No. 12) must meet allows for more than 25,000 seconds of continuous Sun viewing. That's 6.9 hours!

So despite much online nonsense, it's scientifically settled that you can safely either purchase any Sun filter that meets international standard ISO 12312-2, or else use a shade 12, 13, or 14 welding filter. But which shade is best?

Glad you asked. During the last eight years of total eclipse tours, we've offered guests a choice between a 12 and a 14 the day before the event. Hundreds of people compared the two. The result: Nobody wanted a shade 14. The view, they all felt, was unpleasantly dark.

Still, my opinion is that 12s, while safe, give a slightly glaring image. Not bothersome, just not ideal. So I ordered a bunch of the rare 13s and we used those for the 2019 Chile solar totality. Perfection at last! But was it just our opinion?

This past February, I sent a 12, a 13, and a 14 filter to this magazine's staff and asked if they'd look at the Sun and vote on which image they liked best. The result: They prefer the 13s, too.

Now you know what to buy if you want to follow the "in" crowd.

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OH, THE SPACES WE'LL GO

In the second age of exploration, future astronauts will capture breathtaking vistas no earthbound photographer could ever dream of.

BY SETH SHOSTAK

SMALL STEP
ABOVE: Buzz Aldrin took this famous image of his bootprint on the Moon as part of an experiment led by scientists studying the mechanics of lunar soil. NASA

FIRST MEN
LEFT: Neil Armstrong snapped this iconic portrait of Buzz Aldrin standing on the Moon next to the Lunar Module *Eagle*. Armstrong is visible in the reflection on Aldrin's helmet, making this the only photo staged to show the duo together on the lunar surface. NASA

IN THE LAST DECADES OF THE 15TH CENTURY, Western Europe experienced a metaphorical Big Bang — a sudden explosion of geographical knowledge that was later dubbed the Age of Discovery. Improved sailing ships carried profit-minded crews into uncharted seas, revealing the full extent of Earth.

In 1450, world maps drawn in Europe had only a few sketchy indications of West Africa and the Far East. But over the span of a single human lifetime, geographic knowledge grew faster than bamboo. Our understanding of where and how the continents were arranged was completely transformed. Explorers and merchants visited and mapped the majority of the temperate world's coastlines. Globes became something more than minimally useful household furniture.

The Age of Discovery was the product of a special time, a period in European history when it was barely possible — and still highly dangerous — to chart the world. It could not have happened earlier because it depended on improvements in shipbuilding that allowed repeated crossings of the oceans. A century later, with yet better technology, replicating these accomplishments became trivial. There is always a "right time"

for pioneers who, by definition, work at the edge of the possible.

While you may think that, logically speaking, there can only be a single Age of Discovery, that's not true. We are currently concluding the first Space Age, marked by landings on the Moon and robotic forays to other worlds. By the end of the century, we will enter a second Space Age: an extended period during which humans will undertake our own exploration of the solar system. As humanity develops the ability to travel to and wander around nearby worlds, we will see and photograph spectacular landscapes and novel views that will come to define our nearby space environment. The solar system will be captured in a series of iconic scenes, a collection of images that will shape how we think of our own galactic neighborhood.

But wait! Hasn't that already occurred? Haven't we already seen what the solar system has to offer?

We've made a start, beginning with the Apollo Program and its beguiling, close-up photos of our natural satellite. The standouts in this collection include the imprint of a boot in the lunar dust and Neil Armstrong's full-body portrait of Buzz Aldrin in

CLOCKWISE FROM LOWER LEFT:

EARTHRISE
One of the most influential photographs ever taken, Bill Anders' *Earthrise* from Apollo 8 captures our planet as, in the words of crewmate Jim Lovell, "a grand oasis in the big vastness of space." NASA

CHARTED
The Camaldolese monk Fra Mauro created this *mappa mundi* (medieval European world map) around the year 1450. It measured nearly 8 feet (2.4 m) on each side and is one of the most significant maps in the history of cartography. The map was oriented south-up; flip it upside down for a more familiar view. MUSEO CORRER

LUNAR PEAKS
Montes Apenninus, or the Apennine Mountains, lie on the southeastern border of Mare Imbrium. They contain Mount Huygens, the highest mountain on the Moon. NASA/JPL-CALTECH/ARIZONA STATE UNIVERSITY

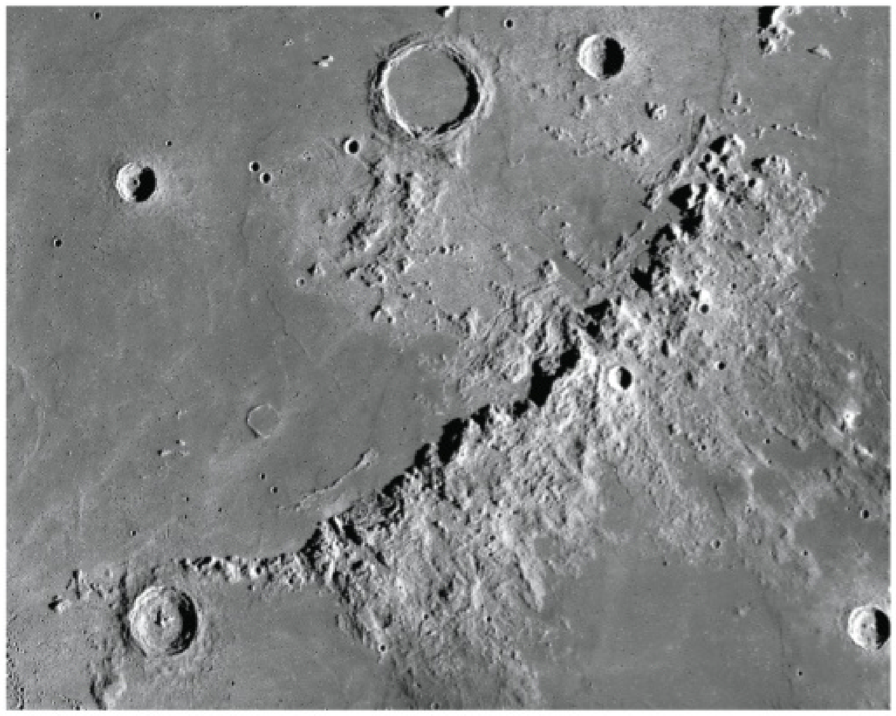
ALPINE EXCURSION
On Apollo 15, astronauts David Scott and Jim Irwin scaled the lower slopes of Mount Hadley Delta in the Apennines with the lunar rover, driving to a height of roughly 300 feet (90 m) above the surrounding terrain. NASA/MIKE CONSTANTINE

his helmet and space suit. Behind Aldrin are the dusty hills of what he called a "magnificent desolation." It was a visual statement that humans had made their first foray into the final frontier.

We still don't have equivalent photos of humans on Mars, although orbiters and rovers have given us close-up views of the Red Planet's topography for half a century. To those you can add a few detailed photos of a small patch of Venus, various flyby portraits of fragile-looking asteroids, and, of course, broad-brush views of planets and satellites taken from distances of a few thousand miles or more. Thumb through any astronomy textbook and you will see all of these things.

However, with the exception of photos snapped by astronauts, our pictorial inventory of the solar system has been made with the dead eyes of cameras bolted to uncrewed spacecraft or rovers. Yes, they can document a scene, but they can't gauge the emotional tug of the pictures they make.

But as we develop the



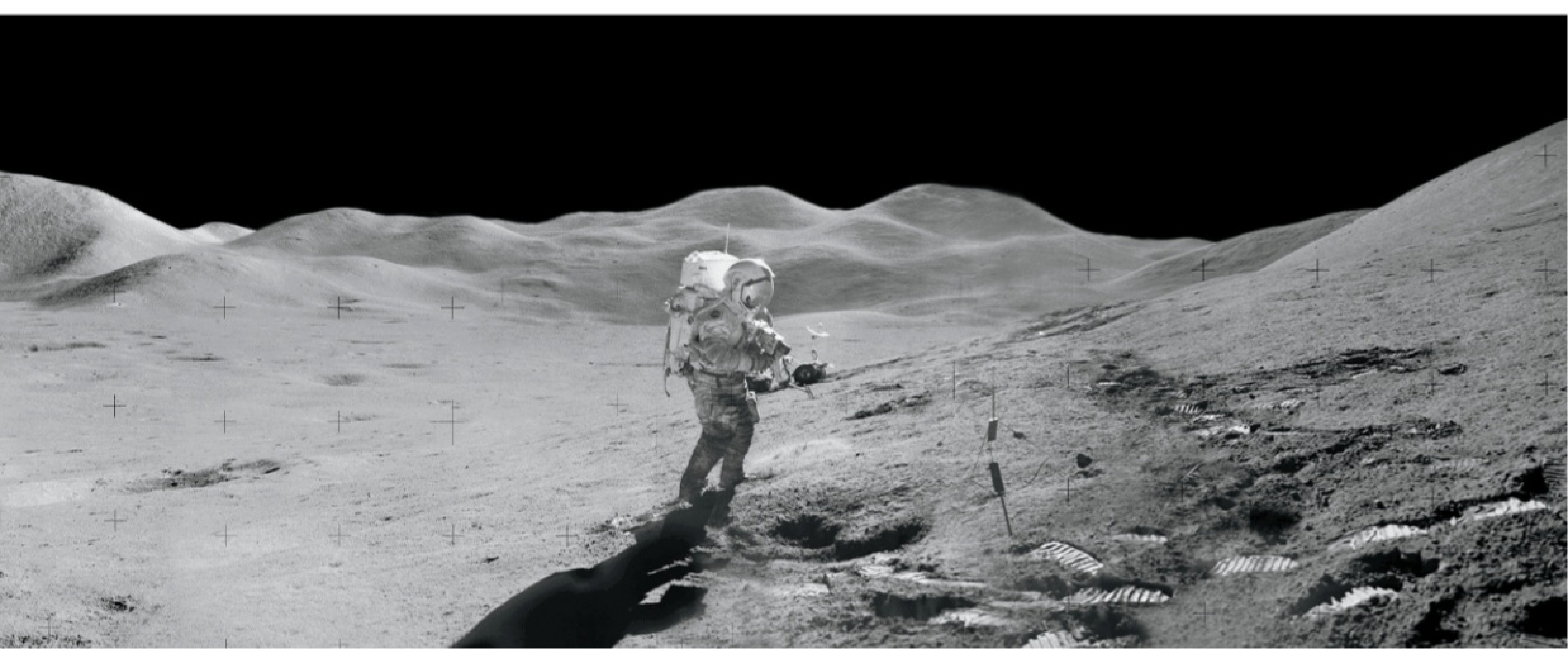
ability to travel to other solar system worlds, we will inevitably stumble into vistas that will resonate with us: stark panoramas that capture a feeling of astonishment and images that don't just show us a landscape, but take us there. This, the "visual poetry" of exploration, may not do much to further our scientific understanding. But it will surely continue to stoke our enthusiasm for venturing beyond our natal world. The best of these images will become tokens of our wanderlust — not to mention reliable moneymakers in the gift shops of planetariums and space centers.

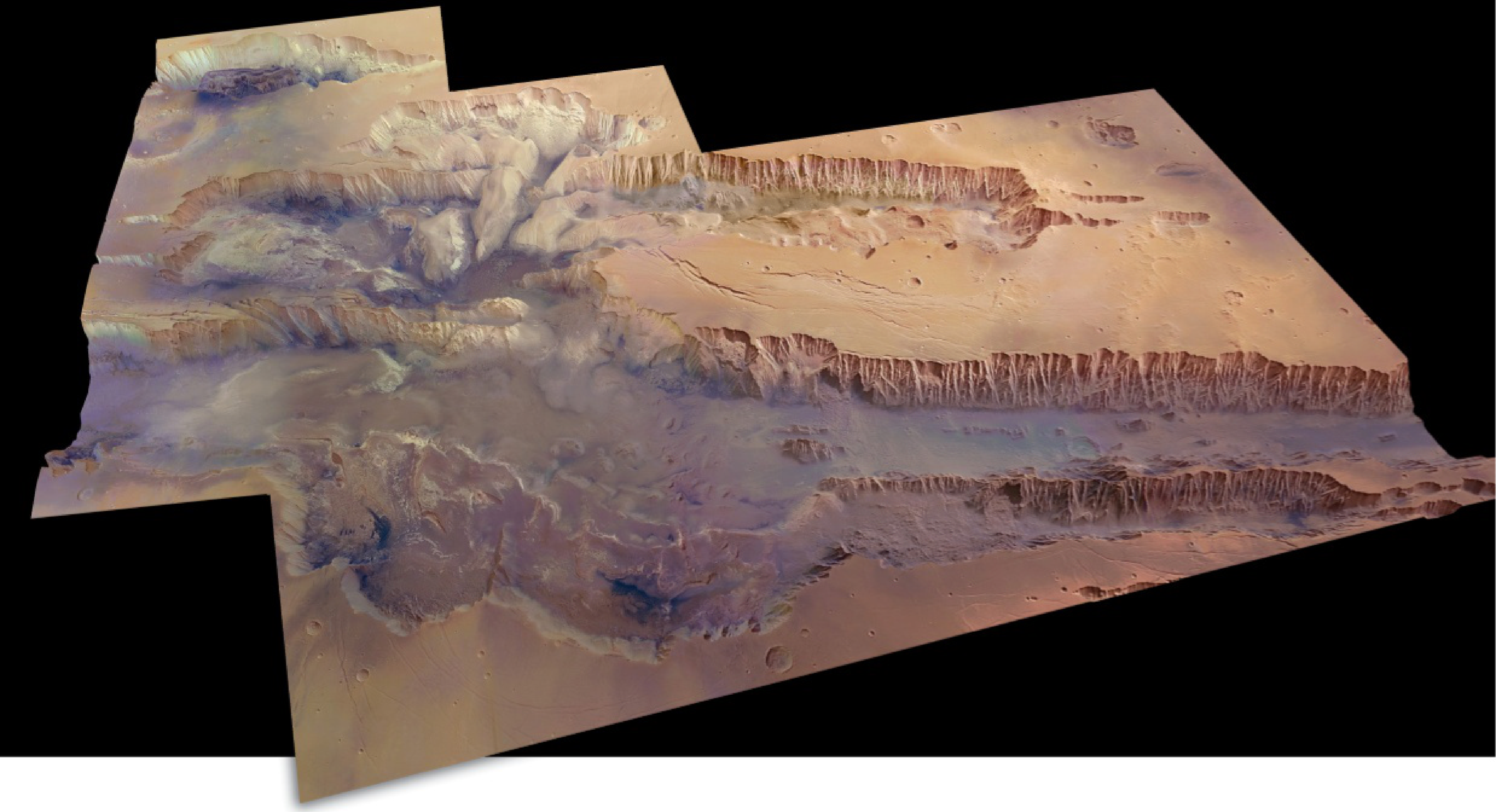
Lunar landscapes

It might seem silly to assign much worth to the emotional power of photos made by future astronauts. Scientists will argue that only experimental results count, and beautiful pictures are little more than frill. If cameras are part of an experiment, they're valuable only insofar as the resulting pictures can be quantified — accurately measured, scaled, and calibrated to produce useful numbers. But that's a sterile view of science, akin to pretending that styling has no relevance to automobiles.

As an example of how art matters, consider the photograph made by Bill Anders Dec. 24, 1968. He and fellow astronauts Frank Borman and Jim Lovell were orbiting the Moon — the first humans to do so — on Apollo 8. As they rounded the lunar farside, Anders saw the disk of Earth edging above the horizon. Sensing a "Kodak moment," he grabbed some color film, loaded it into his modified Hasselblad 500 camera, and snapped away. The resulting photo, *Earthrise*, is one of the most recognizable pictures ever taken. It is more than a striking photo of two worlds. It shows Earth as a jeweled ball, lost in an ocean of empty darkness.

Although about 6,000 photos were snapped by the favored few chosen to make giant leaps for humankind, these images were as much documentation as artistry. But imagine the future, the pictorial possibilities if you dared to hie yourself up





Mount Huygens, the Moon's tallest peak. It's an 18,000-foot (5,500 meters) climb, and you'll require a special suit and an oxygen supply (it will be BYOO no matter where you venture beyond Earth).

Mount Huygens rivals Mount Kilimanjaro in height, although it can claim considerably less wildlife. And because Mount Huygens is a member of a chain, Montes Appenninus, there would be satisfying views of lesser peaks to either side. There would also be vistas across broad, flat areas, including Mare Imbrium, the Sea of Rains. On Earth, the rule of thumb is that it takes an hour to climb 1,000 feet (305 m). So, you would need to allow two days to clamber to the top of this dusty massif.

Another point: Because the Moon has a diameter that's little more than ¼ that of Earth, the horizon will be closer. Even from a mountain, you won't surveil a huge swath of territory. On Earth, the horizon seen from an 18,000-foot (5,500 m) mountain is about 164 miles (264 kilometers) away. On the Moon, it is 86 miles (138 km). On smaller worlds, it will look as if there's an edge over which you might fall, especially as the horizon won't be blurred by haze.

Martian terrain

It's safe to say that the best Moon pictures are still to be made. But if you find the idea of Moon photos too old-timey, there's always Mars. Imagine recording Mars' crevassed and cracked terrain as it extends in all directions from the base of the solar system's highest perch, Olympus Mons. That would undoubtedly be a picture suitable for framing.

Olympus is an inactive volcano more than twice the height of Mount Everest. Its highest reaches would offer you the sight of level topography as far as 240 miles (386 km) away. Given that this is the tallest mountain in the solar system, however, it may someday become entirely too popular and, like Everest, crowded with climbers.

Roughly a thousand miles from Olympus are three other volcanoes on Mars' Tharsis Bulge: Ascraeus, Pavonis, and Arsia Mons, lined up like the stars of Orion's Belt (or, if you prefer, the large pyramids at Giza) and spaced by roughly 500 miles (800 km), one to the next. This set of volcanic pinnacles would make a lovely, iconic composition from orbit, looking obliquely down the line at sunrise or sunset — at least until the next global dust storm sets in. If you ventured to their summits, you could look down into their central calderas — each broad enough to swallow the New York City metropolitan area.

There's an alternative to schlepping a camera to altitudes where the martian atmosphere is thinner than the veneer on cheap furniture: a descent into the mother of all canyons, Valles Marineris. This is the only "canal" that Percival Lowell could possibly have seen with his 24-inch refractor in Flagstaff more than a century ago. It's well-known for being five times deeper than

CLOCKWISE FROM LOWER LEFT:

THARSIS BULGE
Olympus Mons dominates the foreground of this image taken by ESA's Mars Express orbiter, with Ascraeus, Pavonis, and Arsia Mons lurking in the background. ESA/DLR/FU BERLIN/J. COWART, CC BY-SA 3.0 IGO

GRANDEST CANYON
There would be no shortage of stunning vistas of Valles Marineris for any astronauts who explored it. This oblique view was constructed from imagery and terrain data (exaggerated by a factor of four) from ESA's Mars Express mission. ESA/DLR/FU BERLIN (G. NEUKUM), CC BY-SA 3.0 IGO

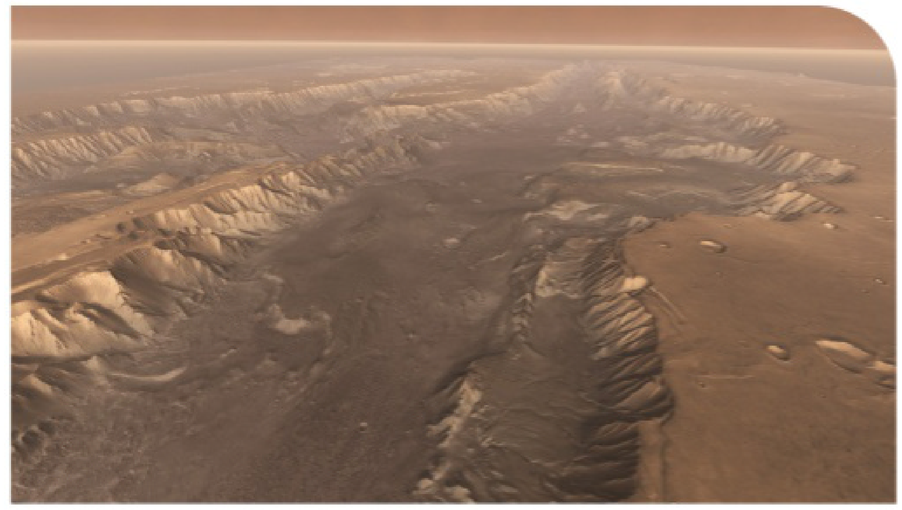
AERIAL TOUR
The walls of Valles Marineris lie roughly 100 miles (160 km) apart in this high-altitude view generated with data from NASA's Mars Odyssey mission. NASA/JPL/ARIZONA STATE UNIVERSITY

MODEST MOON
Saturn's 72-mile-wide (116 km) moon Epimetheus appears to hover above the planet's A and F rings, cutting across the frame. In the background lies the hazy disk of Titan, Saturn's largest moon. NASA/JPL/SPACE SCIENCE INSTITUTE

the Grand Canyon and longer end-to-end than Route 66. This might strike space agency bureaucrats as terrain too risky for a rover.

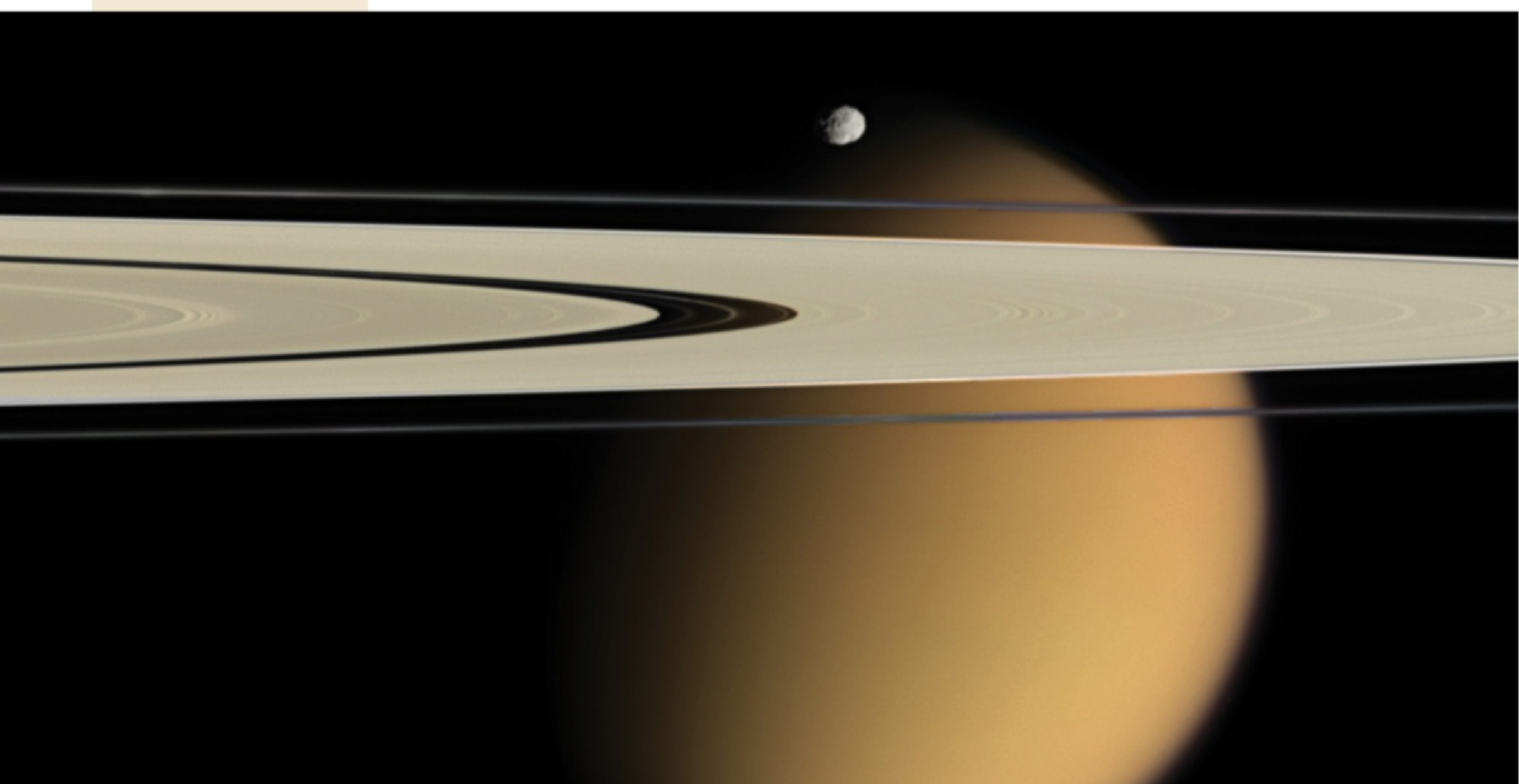
But if you're willing to find your way to the floor of this canyon, you could take some unique photos by standing near one of its 4-mile-high (6.4 km) walls. Positioning yourself in the middle of the main channel might be disappointing, however, as the walls would be some 20 miles (32 km) away and difficult to discern. Of course, there would always be the novelty of stepping in a puddle or two of liquid water, made possible by the higher atmospheric pressure on the canyon floor.

In fact, when considering where award-winning photos might be taken, Mars is perhaps too easy. Images from the orbiting $40 million HiRISE (High Resolution Imaging Science Experiment) camera show details down to a foot (0.3 m) in size, good enough to direct you to some of the best picture opportunities. And rovers trundling across the dusty regolith have made snaps that are comparable in detail and dynamic range to those made with a cellphone. Even though rovers have yet to investigate much Red Planet acreage, their photos have already given an idea of the lay of the land. With a surface sculpted and shaped by 40 million centuries of fast winds, this modestly-sized world is undoubtedly a photographic paradise, a planetwide national park.



Distant worlds

Before quitting the inner solar system, let's consider vistas that await anyone brash enough to challenge the torrid and foggy environment of Venus. Earth's sister planet is swathed in an atmosphere of uninviting carbon dioxide, seasoned with clouds of sulfuric acid. The cloud layers begin in earnest 30 miles (48 km) above the planet's surface and extend to an altitude of about 56 miles (90 km). Within the main cloud deck, visibility in this pea-soup atmosphere would be



limited to a few miles — if there were anything to see up there in the first place. All of which suggests that until you get down onto the crispy surface, photos will be tediously blank and bland.

But there's an exception to that. Get yourself a dozen or so miles *above* the main layer of clouds, and you will behold a spectacular vista at sunrise or sunset. Lying underneath your photographic perch will be a hummocky, yellow-white carpet — the roof of the cloud deck — stretching a few hundred miles in every direction. This is the reality of a runaway greenhouse effect, seen up close and personal, and unrivaled anywhere else in the solar system (as yet).

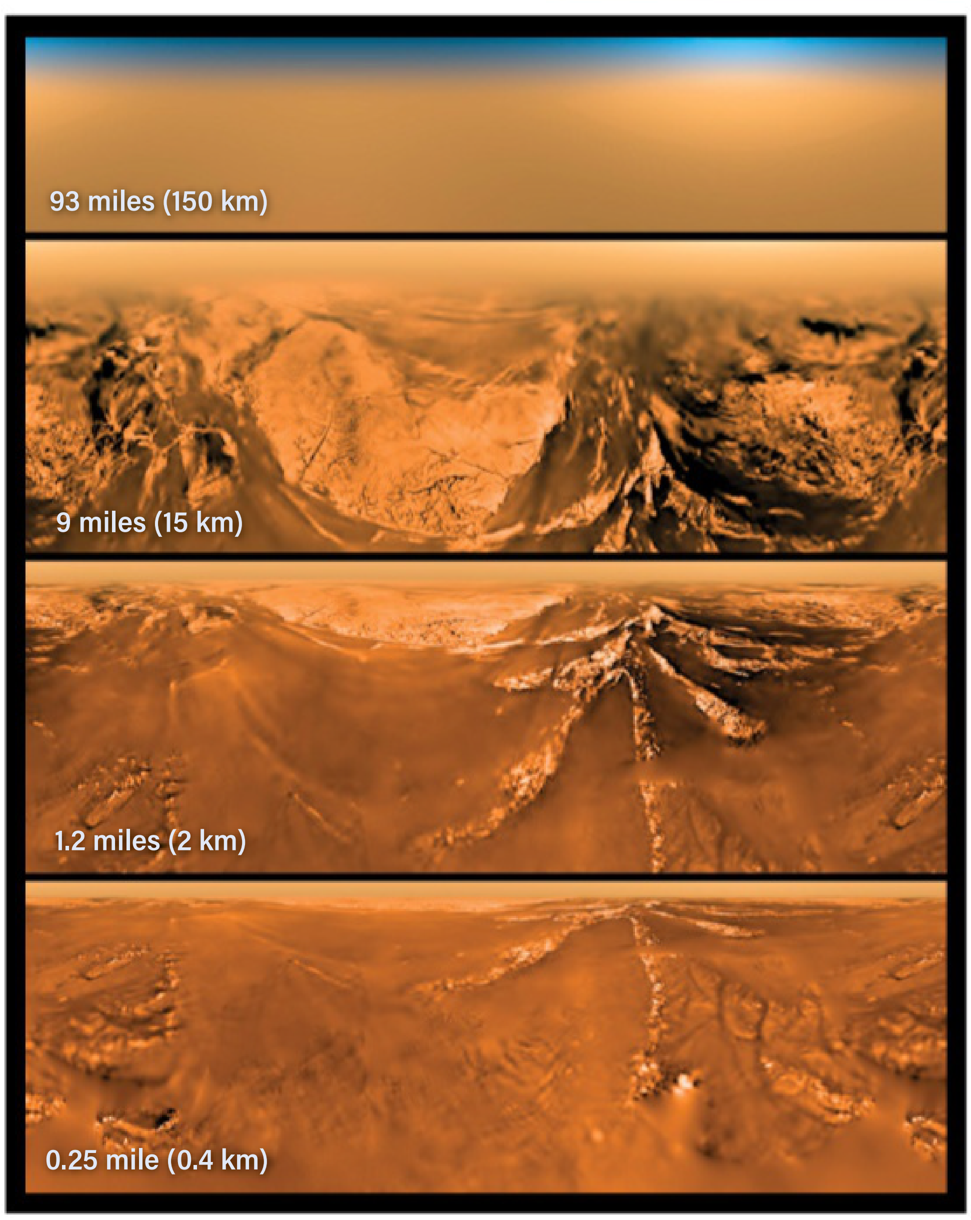
Heading out into the solar system, once Mars is in the rearview mirror, all hard-surface real estate will be limited to asteroids, planetesimals, or moons. But the gas giants are no less stunning. Beginning about 50 years ago, our spacecraft started showing us views of the jovian and saturnian systems. Both are unquestionably spectacular, even though photos of them have all been made from at least 2,000 miles (3,200 km) above their colorful atmospheres.

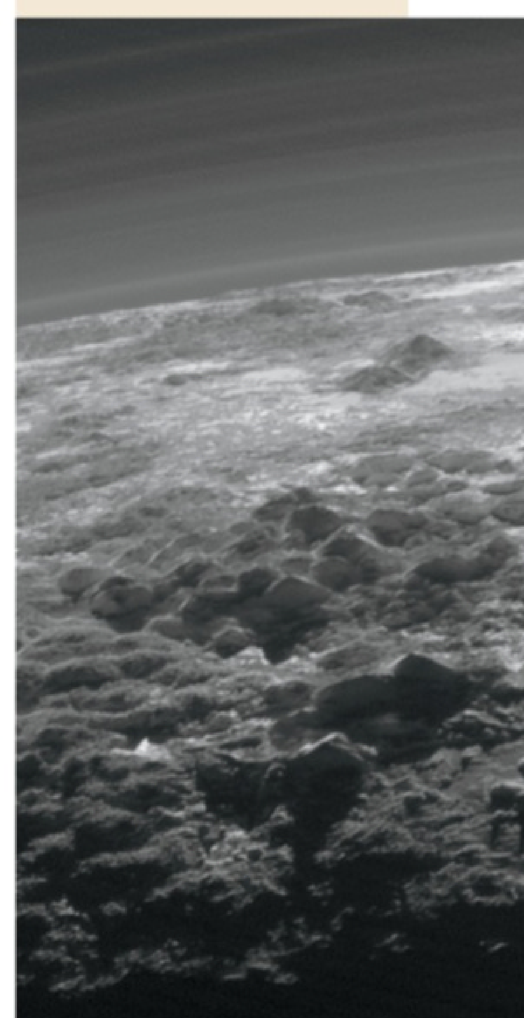
Jupiter and Saturn are each accompanied by ragtag hordes of moons, many of which have their own personalities. A pleasing pictorial arrangement of one or more of Saturn's moons together with the planet and its ring system spanning the frame would be a real conversation starter in your game room.

For astronauts seeking solid ground, the choicest aesthetic pickings in these distant realms are hard to guess. This is largely because the smallest details we've been able to record of objects beyond the asteroid belt are typically 0.5 mile (0.8 km) in size or larger. (Let's except the ground-level pictures of Titan made by the Huygens probe in 2005.)

But among the features we have seen, perhaps the most alluring are the ice mountains on Pluto, imaged by the New Horizons spacecraft. These hard-as-granite peaks are large enough that you could see them from the vicinity of Pluto's moon Charon with a decent pair of binoculars. If you can withstand Pluto's nippy temperatures (a bracing –387 degrees Fahrenheit [–233 degrees Celsius]), you might go down to its surface to line up a telephoto shot of a few mountains framing Charon, hanging low in Pluto's black sky. Charon would be about seven times the apparent diameter of our own Moon.

As a somewhat more ambitious photographic





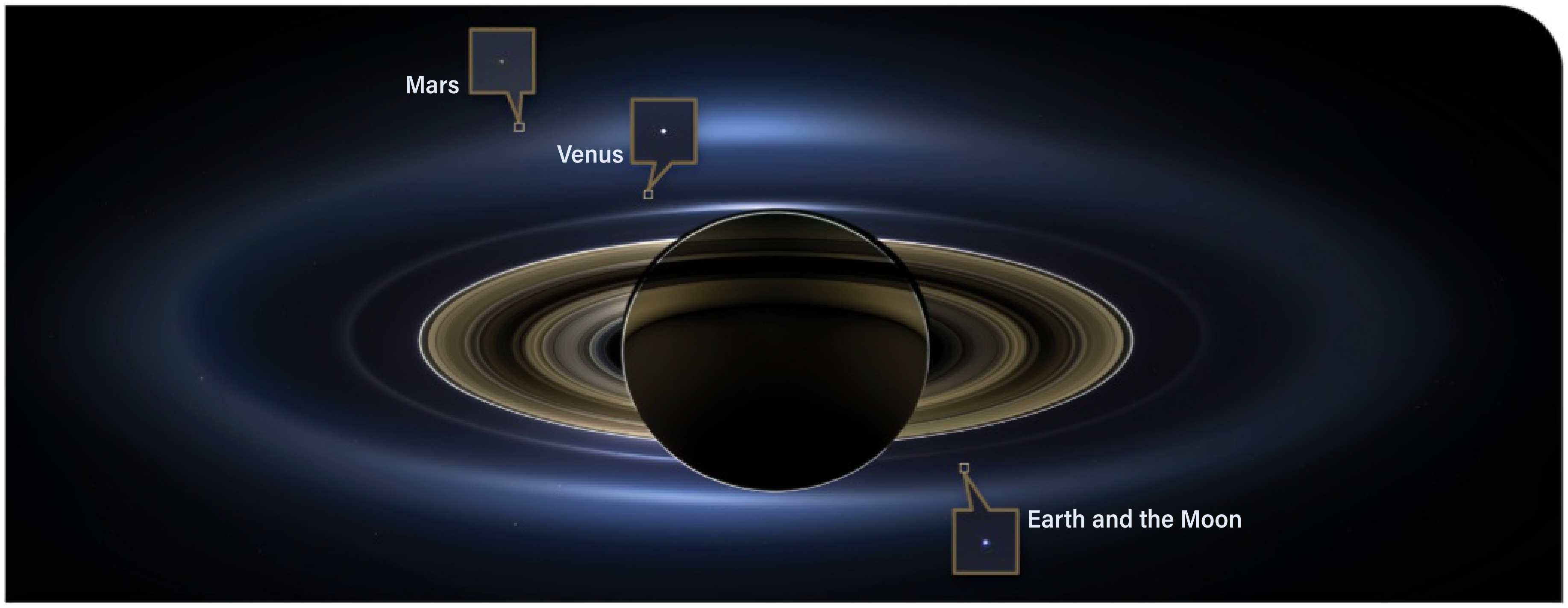
CLOCKWISE FROM LOWER LEFT:

HAZY CONDITIONS
ESA's Huygens probe captured these panoramas of Titan as it descended through its atmosphere Jan. 14, 2005. ESA/NASA/JPL/UNIVERSITY OF ARIZONA

TITAN FIRMA
When Huygens touched down on Titan's surface, it sent this image of what may be a dry riverbed where methane sometimes flows. The ground — and the pebbles that litter it — consist of a mixture of water ice and hydrocarbon ice. NASA/JPL/ESA/UNIVERSITY OF ARIZONA

RING LIGHT
The Sun provides dramatic backlighting for Saturn and its rings in this photograph taken by NASA's Cassini probe in 2013. Venus, Earth, and Mars appear as mere dots in the image. NASA/JPL-CALTECH/SSI

FRIGID WORLD
Pluto's majestic frozen mountains tower up to 11,000 feet (3,500 m) above the icy fields of Sputnik Planum in this image taken by NASA's New Horizons mission. NASA/JHUAPL/SWRI



effort, consider an expedition to roughly 2 billion miles (3.2 billion km) above the ecliptic plane in which the planets orbit. Bayonet a workaday lens onto your camera and aim it downward. You should be able to see the Sun and all the planets out to Saturn. They'll appear only as bright dots. (The Sun will be a *fat* bright dot!) But the fact that the image is real, and not a cut in a book, should lend it a certain *je ne sais quoi*.

The human touch

I've heard space aficionados, including scientists, insist that the future of space exploration won't include much of the freewheeling human wanderings described here. These proudly pragmatic folk maintain that they're only being realistic when they argue that the solar system should be explored and photographed by robots, not people. Humans should simply stay at home and view our cosmic neighborhood from afar. After all, most astronauts insist on round-trip tickets, something that the robotic craft never do.

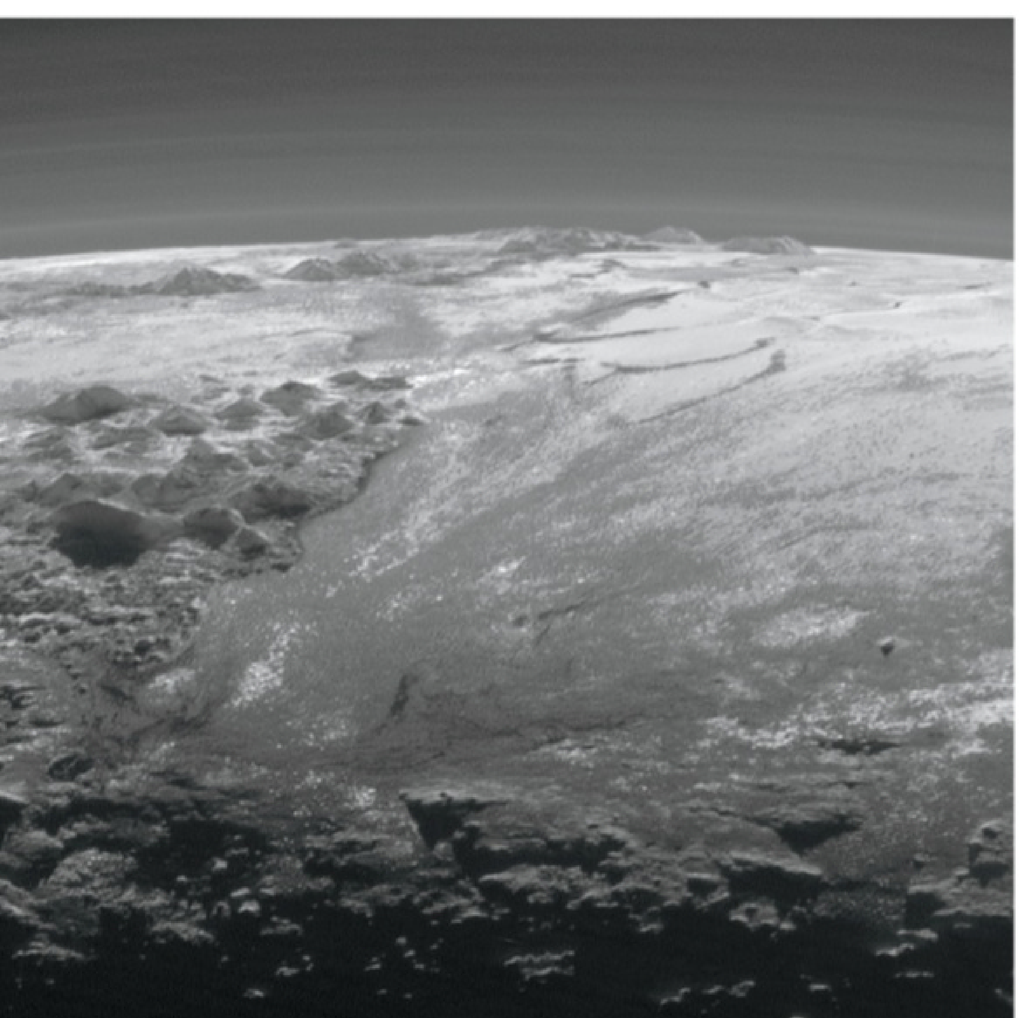
That sounds reasonable, at least, at first. But try walking into a sixth-grade classroom and asking how many of the kids are keen to go into space. You'll find a lot of takers.

Then ask how many prefer to become earthbound engineers, building robotic spacecraft. Many of those hands will go down. Yes, space exploration is a hard, expensive, and dangerous business, so it's only natural to champion a very practical approach — namely, that we tether humans to *terra firma* and leave the exploring to the machines. The latter don't require heavy and complicated life support systems, or shy away from mortal danger.

But clearly, robotic exploration is not the same. Photos made by robot cameras may have tremendous fidelity, but the only artistry they have is that arranged by their earthbound handlers. Arguably better pictures can be made by on-the-spot humans with an aesthetic bent. More than 60 years ago, the Space Age paintings by Chesley Bonestell inspired movies, magazine series, and, ultimately, an entire generation of youngsters who wanted to go to other worlds. They still want to go.

There's something fundamentally different about witnessing nature in person, for otherwise how do you justify muscling a 12-inch Dobsonian out on a cold night to spend hours squinting through a viewfinder? Especially when you could find a *better* picture more comfortably (and with considerably less expenditure of time, money, and effort) online?

It's the romance of going somewhere — to step into a time machine that can take you millions of miles into the velvet voids of space to give you a view that's more than just an image, but an experience.



Seth Shostak *is senior astronomer at the SETI Institute and host of the weekly podcast* Big Picture Science*.*

The floor of Mars' Victoria Crater contains a small field of dunes that appear to ripple up from the otherwise flat, featureless terrain. (As a bonus, the now-defunct Opportunity rover sits just outside the crater rim in the 10 o'clock position on this particular image.) NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA/CORNELL/OHIO STATE UNIVERSITY

DUNES OF THE SOLAR SYSTEM

From Mars and Venus to Pluto and Titan, these windblown features are starting to tell their story. BY NOLA TAYLOR TILLMAN

Dunes of sand sweep across the solar system, building drifts on any world with even the slightest hint of a breeze. Some look like the features we're familiar with on Earth, made up of bits of rock or ice, while some appear far more alien, built solely from organic material. From Mars to Pluto to tiny comets, the wide variety of dunes scientists see may help refine outstanding questions about how dunes form on Earth, along with providing information about past and present conditions on distant worlds.

Studying dune patterns can reveal not only insights about a body's surface composition, but also hint at its atmospheric history. Thinner atmospheres make it harder to toss particles into the air, so ancient dunes can reveal how sand rained from the sky when thicker gases blanketed a world. This can be critical on bodies like Mars, whose hefty atmosphere slowly escaped over time, and Pluto, whose atmospheric density grows and shrinks as it travels around the Sun.

How to build a dune

On Earth, sand is commonly built by eroding quartz. But it can also comprise shells, coral, carbonate, volcanic ash, and even ice. That means sand can develop and settle not only in beaches and deserts but also in the frozen barrens of Antarctica. Furthermore, the definition of sand has nothing to do with composition and everything to do with size and how it is transported: particles that are small enough and light enough to be lofted into the air. On Earth, that's around 0.0025 to 0.08 inch (0.06 to 2 millimeters) in diameter. On other worlds with less gravity, sand particles can be larger.

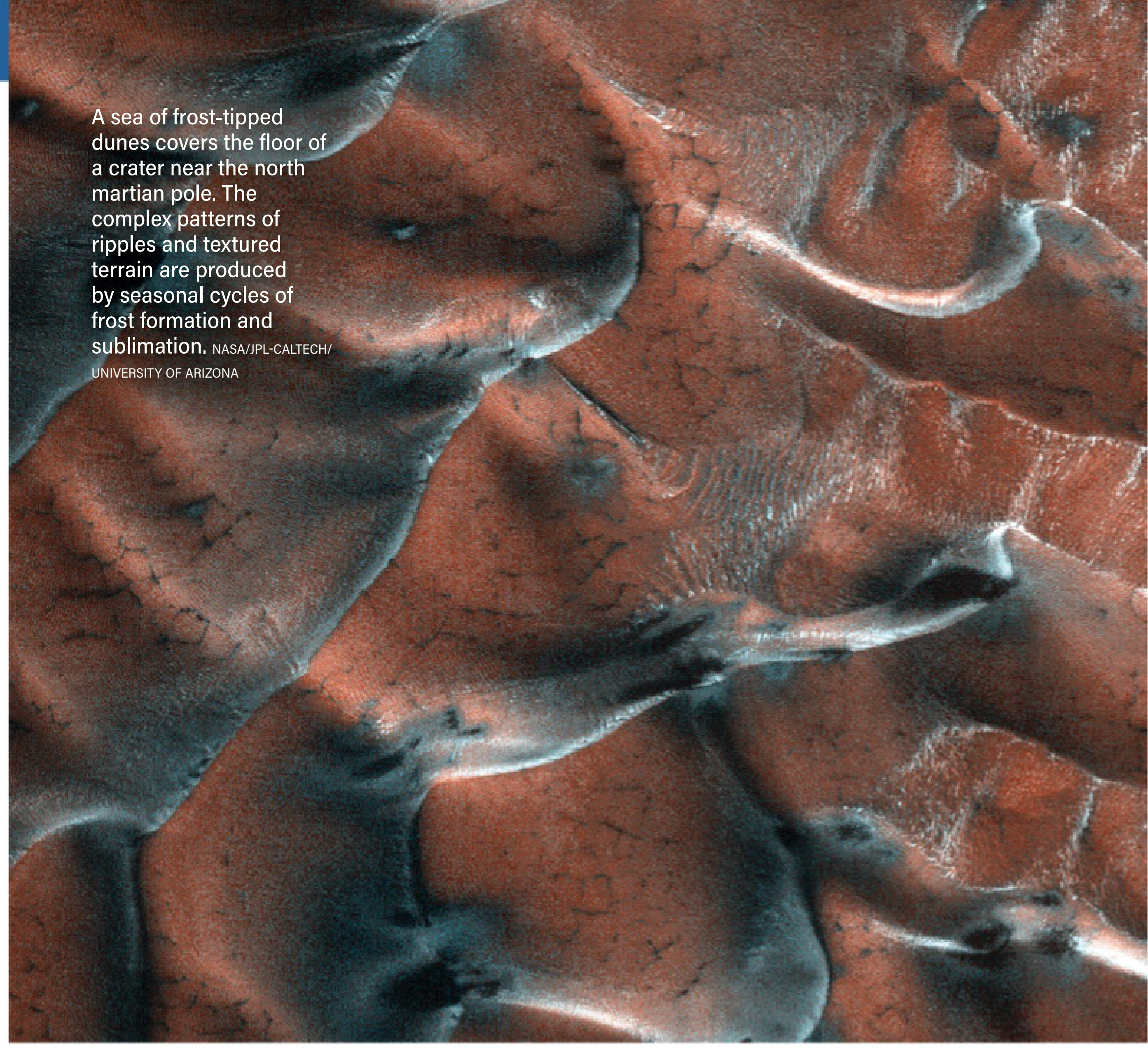
So, how do you go from particles of sand to rippling dunes? The key to dunes is wind. "As long as there's movement of air molecules, we … end up with an aeolian field," or a landscape sculpted by wind-deposited sand, says Jani Radebaugh of Utah's Brigham Young

University. (*Aeolean* refers to the Greek god of wind, Aeolus.)

Despite their compositional variety, dunes on Earth all form under roughly the same conditions and are limited primarily by gravity, which affects how far sand can fly. By looking at the wide variety of dune-covered solar system worlds, scientists hope to get down to the nitty-gritty of how sand dunes form and shift. The basic idea is simple: Wind carries sand across the surface, eventually piling it up in dunes. But the details are where things get messy. Is the sand following a fluid dynamic model, traveling through the air much as it swims through water to create water-sculpted dunes? Or does it obey an impact mechanism model, where the first grain of sand lifted by the wind kicks up other grains that go on to kick up even more?

According to Serina Diniega, a researcher at the Jet Propulsion Laboratory in Pasadena, California, the two models are difficult to distinguish between on Earth because their predicted results look so much alike. But altering the air pressure and gravity — by, say, building dunes on another world — should provide greater insight into which model is correct. "Finding dunes on other bodies, in other conditions, helps discriminate between models that we would not be able to test between on Earth," she says.

Fortunately, there are plenty of dunes in the solar system.



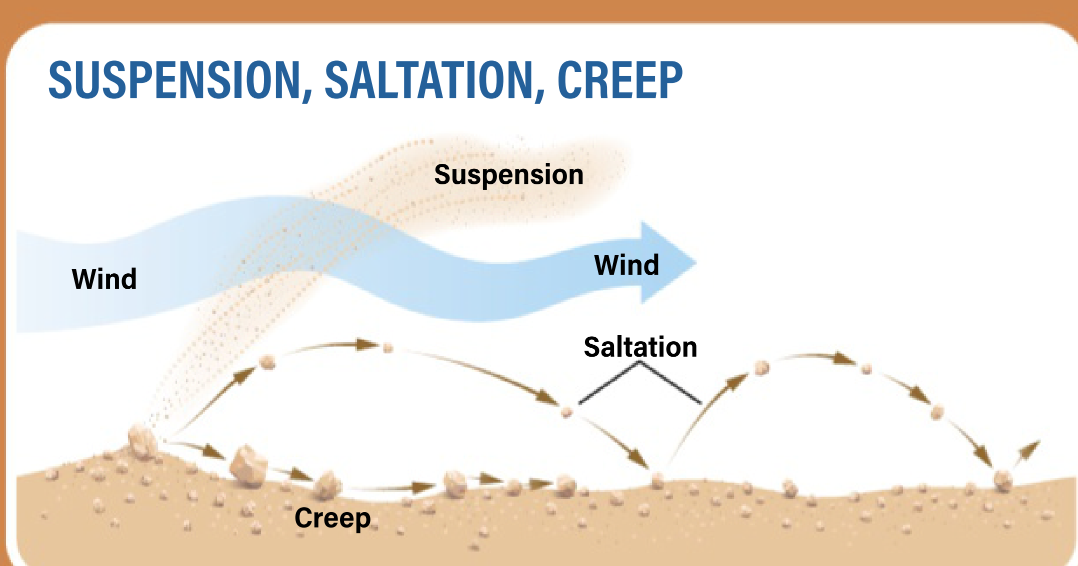
A sea of frost-tipped dunes covers the floor of a crater near the north martian pole. The complex patterns of ripples and textured terrain are produced by seasonal cycles of frost formation and sublimation. NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA

Martian mayhem

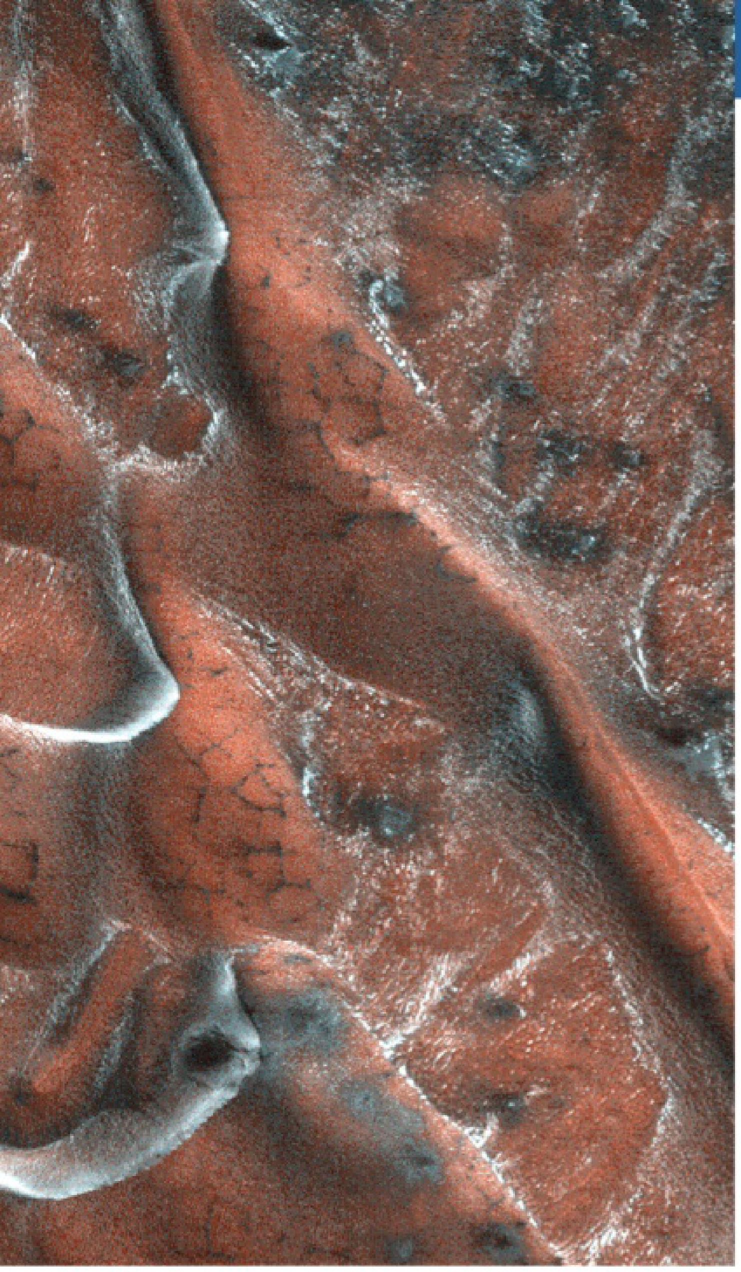
In the early 1970s, NASA's orbiting Mariner 9 seemed to show Mars as a dead, unchanging world similar to Earth's Moon. Only when the Viking missions began capturing higher-resolution images of the Red Planet a few years later did the views reveal active processes, including sand dunes.

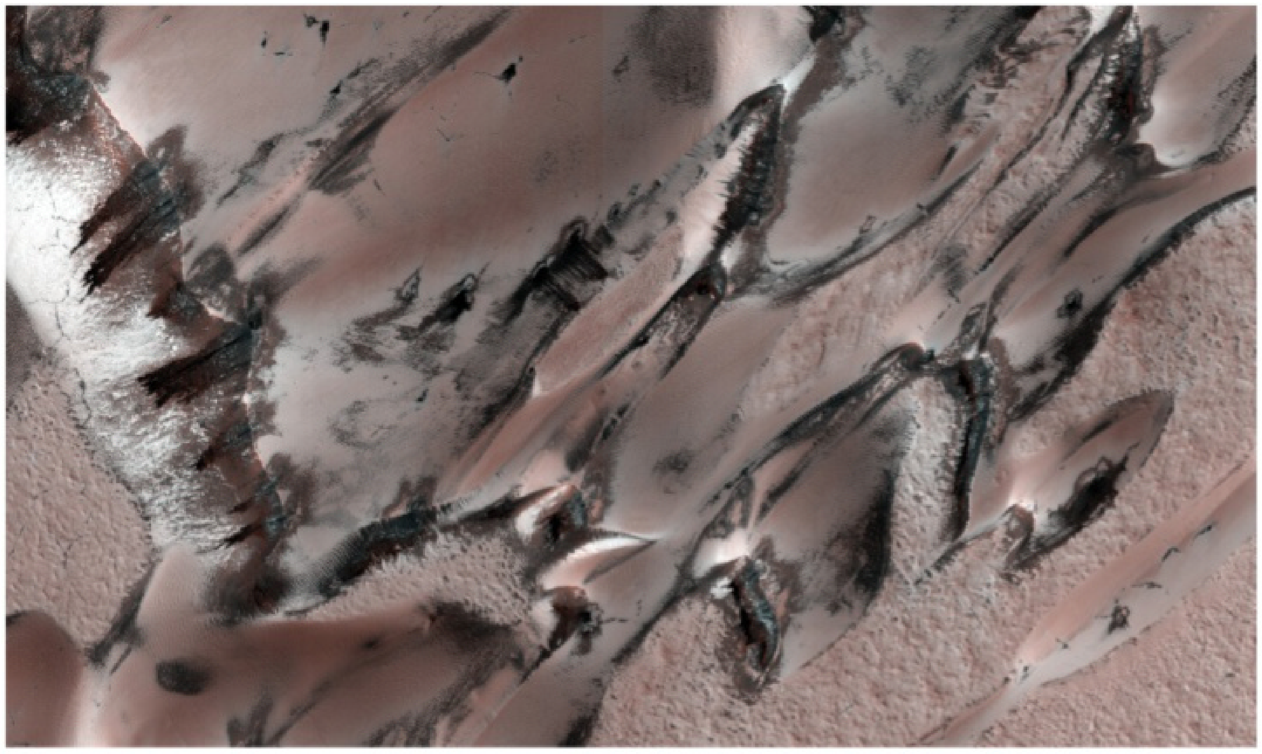
Most martian sand appears to be volcanic in origin. Rocky basalt hurled explosively from now long-dead volcanoes eroded to particles some 0.002 to 0.02 inch (0.05 to 0.5 mm) in diameter over millions of years. Water, which may have flowed briefly across the surface in the distant past, could have potentially broken down some of the rocky material into sand, but today, wind provides the most prevalent source of erosion. Wind is inefficient compared to water when it comes to eroding rock into sand, though. That raises the question of how old martian sand is: Did it all form when water flowed across the surface, or is more sand still being created today? At least some of the sand is recycled as weathered particles form sedimentary rocks that are later turned back into sand — Diniega speculates most of it is — but after sand particles have collided enough times, they break down into dust, which geologists generally define as particles smaller than about 0.0025 inch (0.06 mm). So, the fact that Mars still has sand suggests either low dune motion (few collisions) or that there is more ongoing erosion than currently estimated.

In 2016, NASA's Curiosity rover captured close-up images of dunes,



Sand particles have a characteristic size that allows the wind to pick them up and move them through a series of short bounces, called saltation. Dust particles, which are smaller than sand, move in suspension — the wind picks them up and they remain airborne until it dies down. On the other end of the size spectrum, larger particles creep along the surface, essentially rolling or sliding when blown by the wind without ever being picked up. ASTRONOMY: KELLIE JAEGER





TOP: NASA's Opportunity rover snapped this false-color image of roughly 3-foot-high (1 m) tendrils extending from dunes in Endurance Crater. The lighter-colored dune crests are covered in finer-grained material than the darker, bluish bases, which contain material rich in hematite. NASA/JPL/CORNELL

BOTTOM: In 2017, the Mars Reconnaissance Orbiter imaged this portion of a martian megadune just as northern spring was revving up. Carbon dioxide frost is beginning to sublimate away in the thin atmosphere, revealing the darker sand of the dunes beneath. NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA

confirming predictions based on the planet's characteristics regarding how large sand can grow on the Red Planet. Martian sand is roughly the same size as its terrestrial counterpart, but weaker gravity allows lighter sand to fly, even in the thin air, and form dunes.

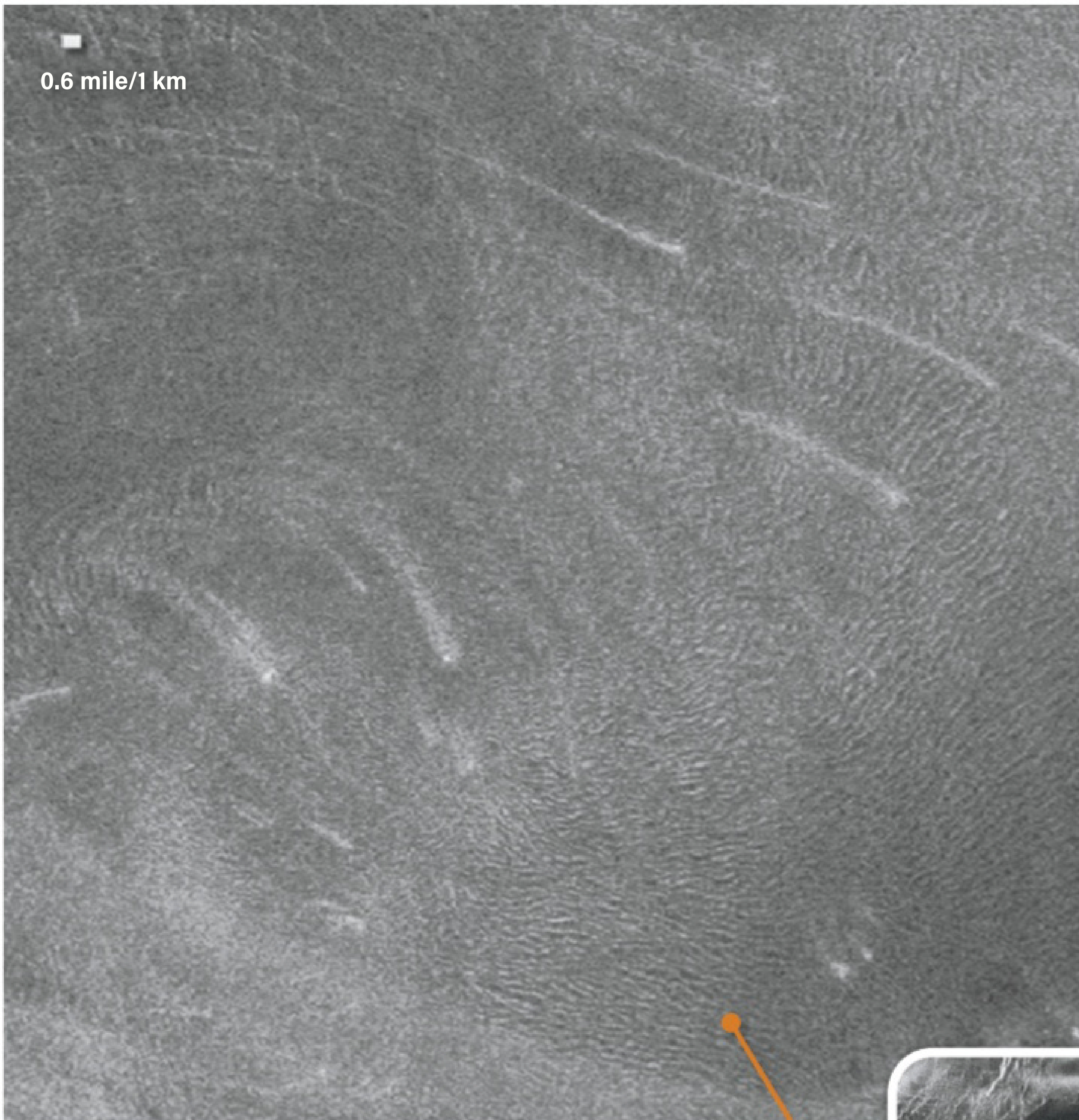
That flight relies on wind speed: Wind tunnel experiments suggest that getting a grain of sand moving on Mars takes a gust 10 times stronger than required for the same grain on Earth. But once the sand starts moving, it's easier to keep it going, thanks to the planet's lower gravity. "The big unknown for Mars is the threshold you need to start the movement of sand," says Simone Silvestro, a researcher at the National Institute for Astrophysics (INAF) in Italy.

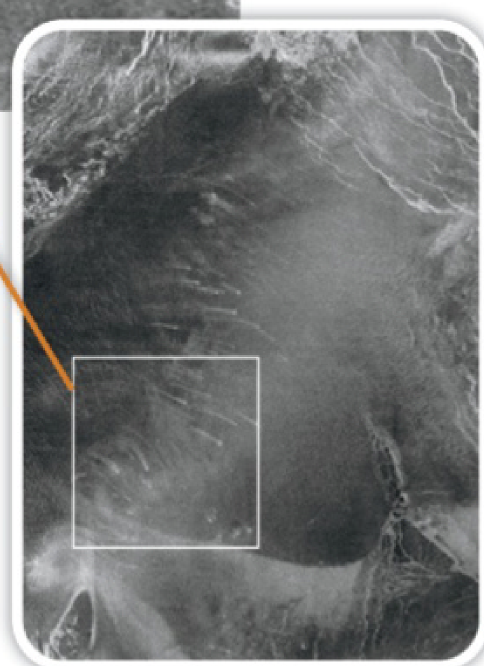
For decades, scientists suspected the dunes they saw on Mars were ancient relics from a past featuring a thicker atmosphere and stronger winds. That changed in 2019, when Silvestro and his colleagues used NASA's Mars Reconnaissance Orbiter to capture dunes creeping along near the martian equator. By comparing images taken more than seven years apart at two different sites, the team determined that these megaripples — which are the largest of dunes at around 3 feet (1 meter) in height — edge along at about 4 inches (10 centimeters) per year.

Even today, scientists aren't certain how strong surface winds are on Mars. They have mapped out global wind patterns based on the topography and how the landscape has formed, but the bulk of atmospheric measurements for the planet have been made by orbiters, which are limited to observing the upper atmosphere. Meanwhile, landers and rovers can only provide wind speed information at ground level; this leaves a wide stretch of sky empty of atmospheric measurements.

Ideally, a rover or lander would sit in one spot and stare at the sand movement constantly, rather than in timed snapshots, Diniega says. That would allow researchers to ground their models in truth. Given that windy, dust-filled air has the potential to clog and damage robotic explorers, it would be even better, Silvestro says, to send people to the planet to measure wind speeds and dune motion.

GETTING A GRAIN OF SAND MOVING ON MARS TAKES A GUST 10 TIMES STRONGER THAN REQUIRED FOR THE SAME GRAIN ON EARTH.





The Magellan spacecraft mapped some 98 percent of the surface of Venus using radar. Small dunelike features, characterized by different reflective properties in the surface terrain, appear in at least two small fields on the planet, including this portion of Al-Uzza Undae. FROM TOP: NASA PLANETARY DATA SYSTEM IMAGING NODE/USGS; NASA/JPL

Vestiges on Venus

Often called Earth's twin, Venus might be the planet you would most expect to sport dunes on the surface. After all, a thick atmosphere can dramatically improve the odds of sand-lofting winds, and the venusian atmosphere is 90 times denser than our planet's. But though Venus' upper atmosphere zips along at a fast clip, surface winds creep by at only a few miles per hour. So, dunes appear sparse on Venus.

But one reason for this paucity may be the lack of good images. Although several missions have been sent to explore Venus, the planet's thick atmosphere makes catching a glimpse of the surface — or surviving on it — even more challenging. Most photos are radar images captured from Earth and from orbiting spacecraft, which aren't comparable to visual snapshots, such as those scientists have of Mars. In the early 1990s, NASA's Magellan mission mapped nearly the entire planet with radar, revealing the first faint hints of two small dune fields. While scientists have speculated radar signals hint to the presence of centimeters-long "microdunes" in the planet's southern regions, clear evidence of such features remains hidden.

Additionally, making sand on Venus is a challenge in itself. That same thick atmosphere dampens the explosive volcanic processes that could create ash to serve as sand. And the planet lacks the liquid water necessary to carve small particles from the rocky surface. Most venusian sand is thought to have formed when impacts struck the surface and threw up material. Even if sand forms, research shows the high temperatures could cause particles to melt together into an unwieldy conglomeration too large to fly in what little wind there is on the surface.

It's also possible that traces of ancient dunes were wiped clean in a planetwide resurfacing event some 500 million years ago. Volcanic eruptions spewed lava across the surface, erasing craters and dunes to create a clean slate only slightly scratched on more recent timescales.

If Venus is hiding dunes, they may soon come to light. In 2021, NASA announced two new Venus missions, VERITAS and DAVINCI, while the European Space Agency revealed plans for a third, EnVision. The trio should begin probing the planet in the 2030s.

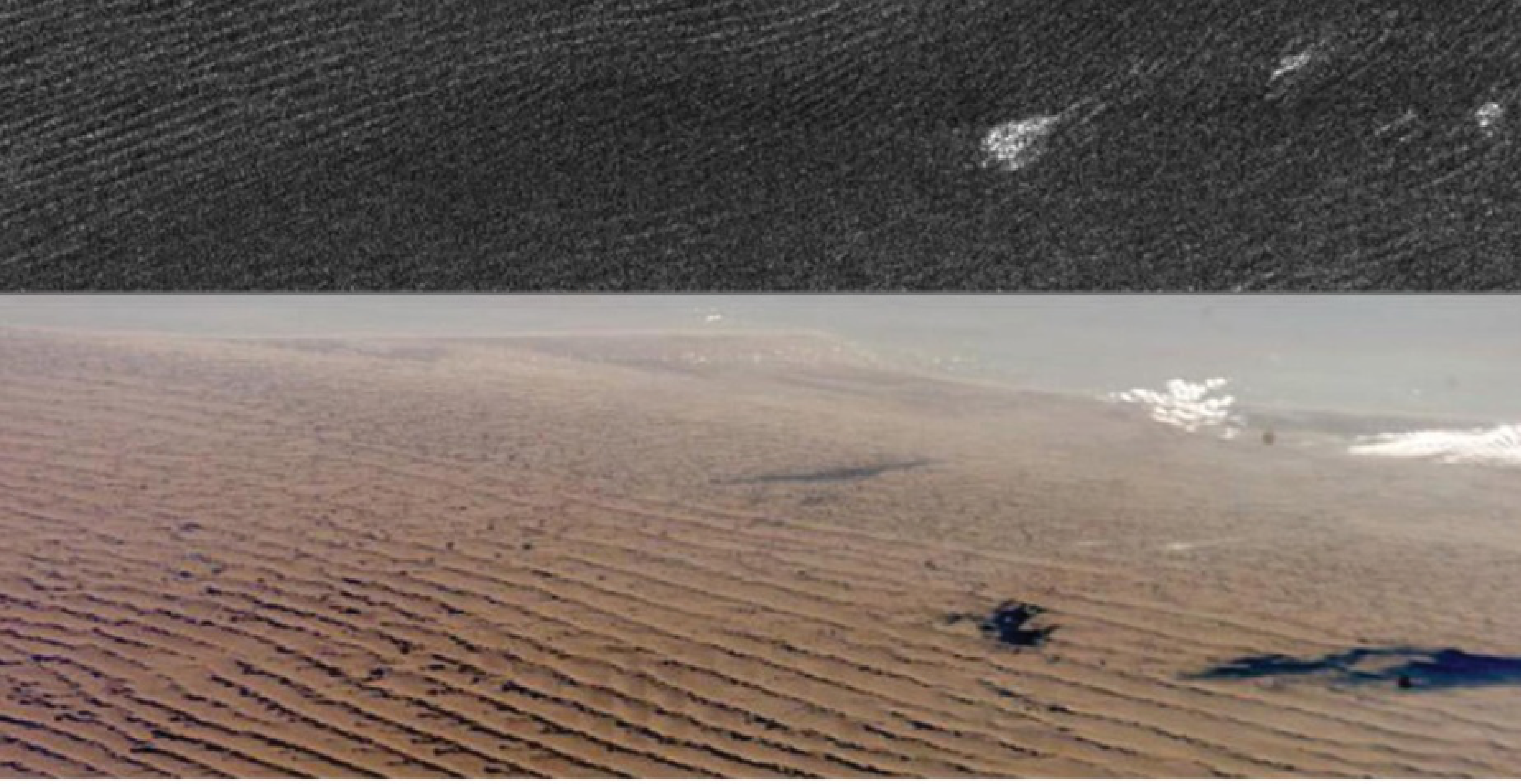
Saturn's satellite Titan

With its organic haze and methane lakes, Saturn's moon Titan is the only world in the solar system besides Earth known to sustain liquid on its surface. But while researchers predicted its lakes of methane and ethane in the 1980s, windblown sand dunes were considered unlikely due to the world's potentially sticky sediments, which are made of tarry hydrocarbons.

So it was a surprise in 2006 when NASA's Cassini mission revealed aeolian dunes spread across the moon's midlatitudes. "They're almost a defining feature of Titan," says Ralph Lorenz, a dune expert at the Johns Hopkins Applied Physics Laboratory in Laurel, Maryland.

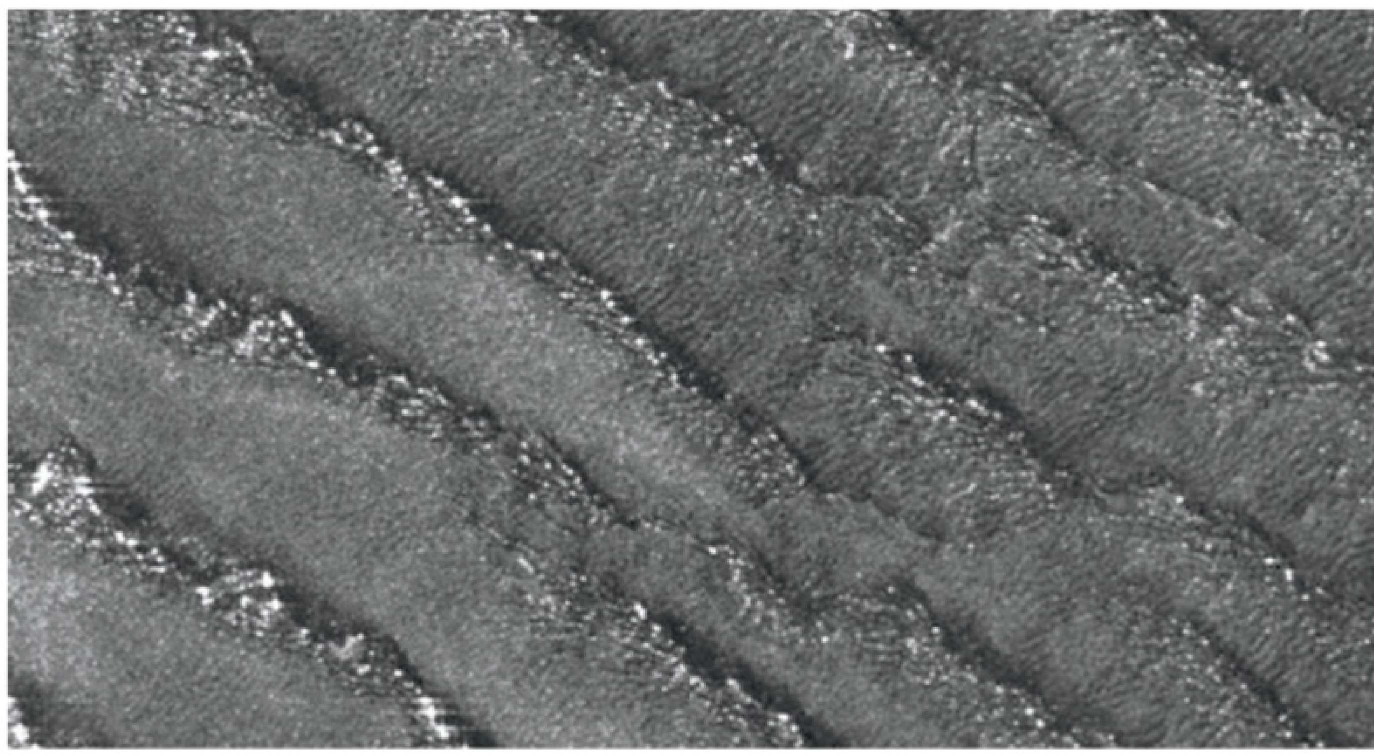
One of the biggest surprises was the fact that Titan's dunes stretch across the surface in the opposite direction from the usual gentle motion of its winds. It turns out that Titan's winds briefly reverse their flow and grow stronger during the equinoxes. These backwards seasonal winds are more likely to create dunes than the lighter breezes blowing the rest of the year.

While sand on Earth and Mars comes from material worn away with time, Titan's sand may rain down from the sky.



LEFT: Dunes on Titan (top), mapped via radar by Cassini, appear similar in structure to those formed in Earth's Namib Desert (bottom). The bright features in the top image are not clouds, but rather terrain that appears lighter in radar imagery. FROM TOP: NASA/JPL; NASA/JSC

BOTTOM: This close-up shows a field of longitudinal dunes on Titan. Planetary scientists believe Titan's dunes could be composed of sticky hydrocarbon sand that may rain down from the sky. UNIVERSITY OF HAWAI'I



Tholins, clumps of organic matter whose precise composition remains a mystery, cover the surface of Titan, making up the clouds and haze in the moon's atmosphere. The material may stick together to form sand-sized particles as it falls from the sky, only to be blown into dunes. But how such processes work with organic material is not well understood.

"The outstanding question at this point is whether there is some kind of aggregation process happening to make haze particles stick together, making sand-sized particles that way," says Sarah Horst, a Titan researcher at Johns Hopkins University in Baltimore.

Alternatively, tholins could form a sedimentary layer that is later eroded by Titan's flowing liquid. Or the sand could instead be composed of material left behind once that liquid has evaporated, like the ring in a bathtub.

Titan's exotic environment makes determining the details of dune formation difficult. According to Horst, who experiments on tholins in her lab, one of the challenges of understanding the strange substance is trying to figure out how organic material behaves at temperatures on Titan: –297 degrees Fahrenheit (–183 degrees Celsius). "A lot of these compounds we're interested in are toxic or explosive or both," she says. While there are plenty of labs capable of handling the temperatures and compounds, including Horst's, the safety concerns raise another issue. "It's a bigger challenge to get funding to do the experiments," she says.

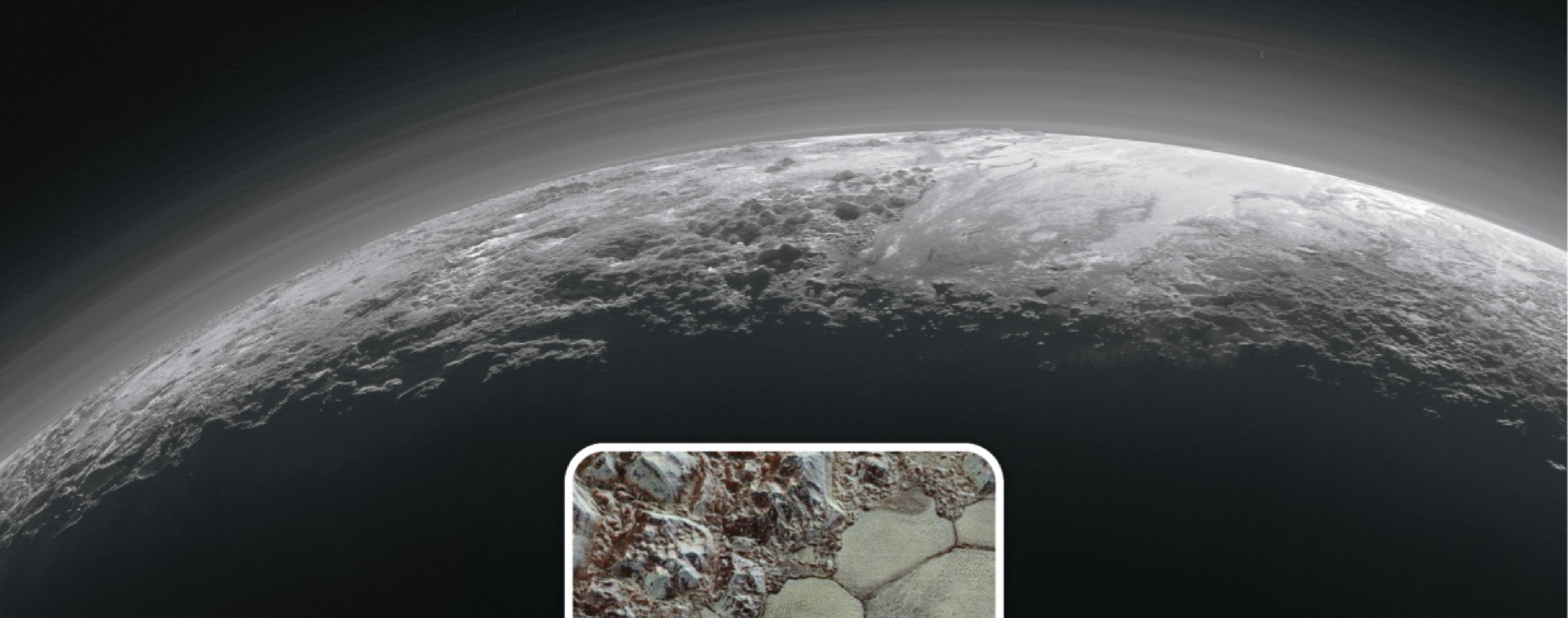
Many questions may soon be answered by NASA's Dragonfly mission, a flying rotorcraft planned to explore Titan in 2034. Horst says Dragonfly should deliver "more complex information about the particles to help find out how they're made."

Because Dragonfly will explore at various altitudes rather than staying stuck on the surface, the mission will be able to take more detailed readings of the atmosphere than are available for other non-terrestrial worlds. That should help scientists understand how tholins are blown across the landscape. And while rovers tend to avoid dunes, where soft sand can bog them down, Dragonfly's ability to soar from one location to another will allow it to study numerous surface features — including, Lorenz expects, dunes.

Pluto's icy dunes

When NASA's New Horizons mission breezed past Pluto in 2015, it revealed a surprisingly active dwarf planet, rather than the dead world many researchers expected to lie at the edge of the solar system. The quick snapshots captured by the spacecraft showed the surface of Pluto has been sculpted by ice relatively recently, and scientists have identified a wide variety of geological features.

MANY QUESTIONS MAY SOON BE ANSWERED BY NASA'S DRAGONFLY MISSION, A FLYING ROTORCRAFT PLANNED TO EXPLORE TITAN IN 2034.



Pluto's tenuous atmosphere, captured here in dramatic backlighting by New Horizons, is likely too thin for its winds to efficiently pick up particles from the ground and blow them into dunes. Instead, researchers speculate that dunes might get their start as methane from the surface sublimates, sending material into the air that is then swept into dunes. NASA/JHUAPL/SWRI

When New Horizons flew past Pluto in 2015, it imaged a geologically diverse world that has intrigued researchers. This image, one of the highest-resolution photos snapped by the spacecraft, shows a portion of Sputnik Planitia, the western half of the dwarf planet's famous heart. Numerous dunelike features appear on the pitted nitrogen-ice terrain at lower right. NASA/JHUAPL/SWRI

Radebaugh was chatting on Facebook with fellow planetary scientist Matt Tefler while the first images of Pluto were released. As they began studying the snapshots, dunelike structures in the heart-shaped feature now called Tombaugh Regio jumped out at the pair. To Radebaugh, they appeared similar to dunes found in Death Valley, California. "It clicked right away: 'Oh, these are dunes,'" she says.

They reached out to the New Horizons team, working with their geologic group to nail down the landforms. After examining the images in more detail than was available during the initial release, they found the features bore more than a passing similarity in shape to dunes. The dunes also aligned well with wind streaks identified by other researchers, suggesting the winds that formed the streaks blew in the same direction as the winds that created the dunes.

As on other worlds, the biggest challenge for scientists is to figure out how Pluto generates the initial lift that gets dunes rolling. Pluto's atmosphere is incredibly thin — likely too thin to pick up particles from the ground. "It's hard to actually get the math to work because the atmospheric density is so low, your ability to transport material decreases," Horst says. So how are the particles taking that initial jump?

Radebaugh and Tefler think the answer lies in a field of small pits near the dunes. Pluto is covered with ice composed of not only water, but also methane, nitrogen, and carbon dioxide. As the methane works its way to the surface, it jumps from a solid to a gas, throwing methane molecules into the air and leaving the small pits. Radebaugh and Teffler think those particles are then swept into dunes by the winds.

Only a portion of Pluto's surface was imaged and of that, just a small part appears to have dunes. Tefler says this may be thanks to the local landscape. "Circulation models suggest that area we're looking at there should be the windiest place on Pluto," he says. "It's a place that, because of the thermal and pressure-driven properties derived by the terrain, is likely to promote wind."

But not everyone thinks there is enough evidence yet to declare the features are dunes. "It's still an ongoing debate in the planetary geomorphological community," says Phillipe Claudin, also at INAF. Tefler and Radebaugh remain confident that what they've spotted are dunes, though it will most likely take another mission to far-off Pluto to confirm the nature of the features.

Common comets

If planetary scientists were surprised to find dunes on Pluto, where the atmosphere is thin, they were floored to find them on the tiny Comet 67P/Churyumov-Gerasimenko, where an atmosphere is all but nonexistent.

Often compared to a rubber ducky, Churyumov-Gerasimenko has two lobes joined together by a neck. This shape is most likely the result of two separate pieces of early solar system material slowly coming together. When the European

ONLY A PORTION OF PLUTO'S SURFACE WAS IMAGED AND OF THAT, JUST A SMALL PART APPEARS TO HAVE DUNES.

Space Agency's Rosetta spacecraft entered orbit around Churyumov-Gerasimenko in 2014, it revealed dunes on the neck and both lobes, raising the question of how an object with little to no atmosphere could have windblown features.

The answer comes from the heart of the comet. As the comet draws near the Sun, icy material from its nucleus begins to convert to gas, working its way to the surface. Along the way, it carries bits of dirt, which are released as the ice sublimates and creates an extremely thin envelope around the nucleus, called the coma. Winds generated by the change in temperature as the comet rotates are strong enough to move the dirt. Gravity is weak on the tiny comet, making it easier to keep large particles aloft. Thus, material from within the nucleus is ultimately smeared across the ground to form dunes "almost automatically," says Claudin, one of the authors of the research reporting these dunes.

Such dunes can only form when the comet is near the Sun. Over its 6.4-year orbit, Churyumov-Gerasimenko spends most of its time in the cooler regions of the solar system, near Jupiter, its surface unchanging. Claudin estimates that the comet only actively forms new dunes for about two weeks every orbit.

But there's nothing particularly unique about Churyumov-Gerasimenko. "I would say what we are seeing is rather generic," Claudin says. That means the thousands of known comets — and billions of estimated ones — may all create dunes of their own when they draw near the Sun. Future spacecraft may be better prepared to probe any dunes that are forming or frozen on the surface.

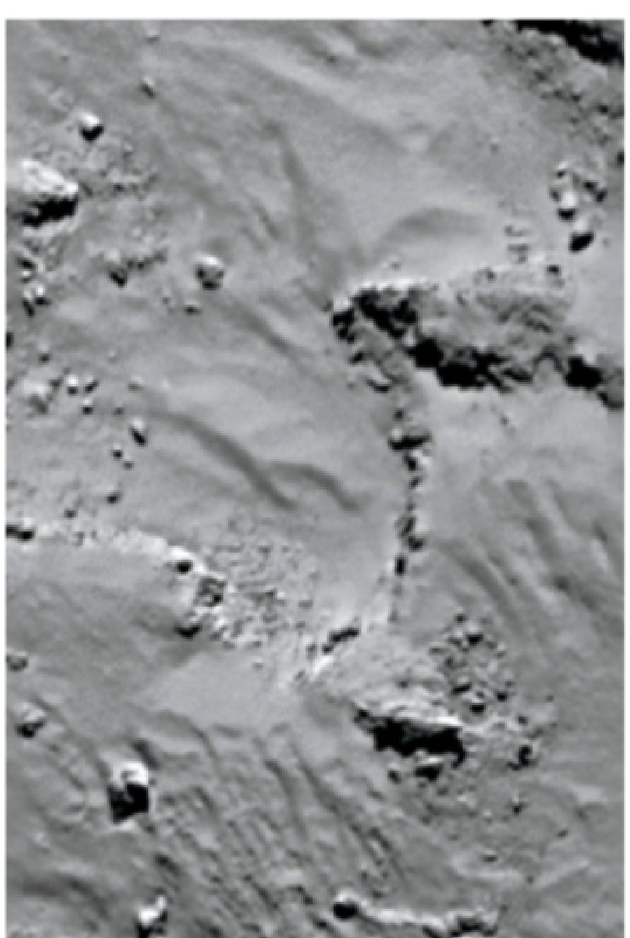
But like a cometary atmosphere, some consider the evidence tenuous. "I've never been convinced," Horst says. She states that a common problem in planetary science is the association between a feature seen on another world and the terrestrial counterpart it resembles. "Just because something looks like a process we're familiar with doesn't mean it is a process we're familiar with," she says. After all, humans like to identify and categorize what we see, but sometimes what we perceive as a particular feature — say, a dune — could turn out to be nothing. Think of the pyramid and face that have been identified on Mars — when examined closely or from another angle, they're just rocks.

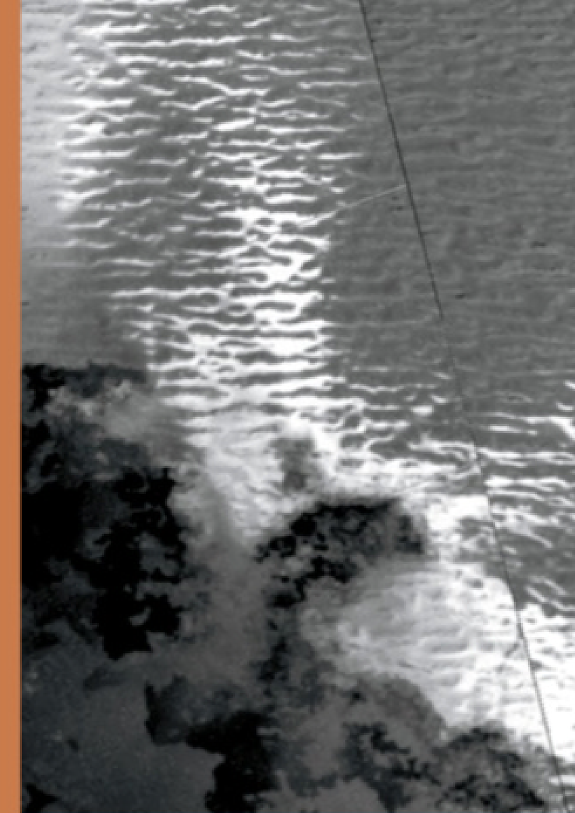
Nonetheless, in a 2017 paper published in *Aeolian Research* discussing how our understanding of dune formation has changed as solar system worlds are studied in greater depth, Diniega, Radebaugh, Silvestro, Tefler, and others argue that recognizing dunes is the first step in identifying them. By setting up a flexible policy for identifying windblown features, the researchers hope to make formerly vague classifications more consistent. Ideally, the identification of dunes on worlds such as Venus and Pluto would follow a similar path to those on Mars. Once a mission observes suspected dunes, the next generation of spacecraft can perform more detailed observations to study their characteristics and analyze patterns of individual candidates to confirm or deny their status as dunes. Subsequent missions can then classify the landscape even further.

And as observations of other worlds (including comets) continue, scientists hope to get a better feel for what is possible elsewhere, allowing them to refine their models of how dunes form and move, on Earth and beyond.

Nola Taylor Tillman *is a freelance writer with a passion for astronomy, planetary science, and space missions.*

When it arrived at Comet 67P/Churyumov-Gerasimenko, the Rosetta spacecraft sent back up-close images of the surface that showed features scientists had never expected to see on a comet — including possible dunes. ESA/ROSETTA/MPS FOR OSIRIS TEAM MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA





Images from NASA's Galileo spacecraft show potential dunes (upper right) on the surface of Jupiter's volcanic moon Io. The dark material in the lower left of this image is recently cooled lava, while the brighter white may be deposits of material from frost vaporized by the lava as it flowed. NASA/JPL-CALTECH/RUTGERS

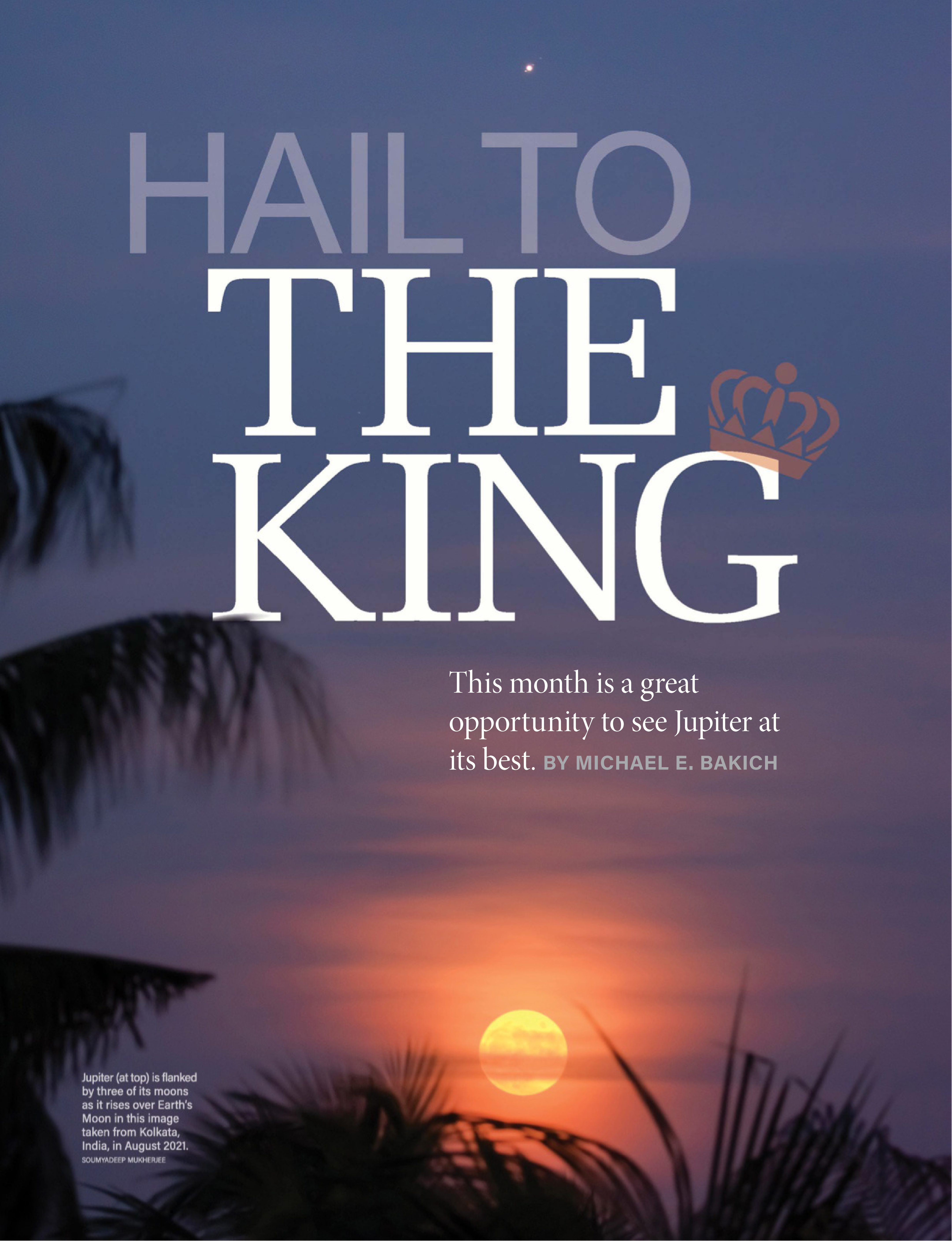
FIRE AND ICE

A recent paper published April 19 in *Nature Communications* has combined 14-year-old imagery from NASA's Galileo mission with models of how grains move to explain how dunes might form on the solar system's most volcanic world: Jupiter's moon Io. The study shows how on this moon, grains of rock or frost are not carried by winds, which are weak in the thin atmosphere. Instead, as hot lava mixes with sulfur dioxide (SO_2) frost underground, the SO_2 turns to gas that vents through the surface. This outgassing is "dense and fast moving enough to move grains on Io and possibly enable the formation of large-scale features like dunes," according to first author George McDonald of Rutgers University in a press release.

And indeed, Galileo did spot dunelike features on the moon. The researchers closely examined the features' dimensions and the spacing between crests, concluding these formations do look like dunes seen elsewhere in the solar system, including Earth. "Our studies point to the possibility of Io as a new 'dune world,'" McDonald said. "This work tells us that the environments in which dunes are found are considerably more varied than the classical, endless desert landscapes on parts of Earth." — *Alison Klesman*

HAIL TO THE KING

This month is a great opportunity to see Jupiter at its best. BY MICHAEL E. BAKICH



Jupiter (at top) is flanked by three of its moons as it rises over Earth's Moon in this image taken from Kolkata, India, in August 2021.
SOUMYADEEP MUKHERJEE

In 2022, Jupiter reaches opposition — the point in its orbit opposite the Sun as seen from Earth — on Sept. 26. It's also the giant planet's closest approach to Earth since October 1963. On the 26th, Jupiter will blaze at magnitude –2.9, making it the brightest starlike object until Venus rises shortly before sunrise.

If you can't observe Jupiter exactly at opposition because of a personal commitment or clouds, don't fret. You'll have plenty of time to see the king of the planets while it's big and bright: At no time from July 20 through Dec. 3 does its magnitude dip below –2.6.

On its opposition date, Jupiter sports an apparent diameter of 49.9", which is quite close to its greatest possible size of 50.1". And between the two dates above, its apparent size is at least 43". So, now is the time to set up your telescope, crank up the power, and observe Jupiter and its moons in all their glory.

Moving right along

Jupiter first entered Pisces in mid-April; then, from late June until early September, it crossed in front of some stars in the northwestern corner of the constellation Cetus the Whale before returning to Pisces. This whole region lacks any bright stars, so it will provide a huge contrast to Jupiter's brilliance. In fact, the nearest 1st-magnitude star, Fomalhaut (Alpha [α] Piscis Austrini), lies nearly 35° away.

For amateur astronomers in mid-northern latitudes, the planet's location in Pisces means it will climb around halfway up the sky — not terrible, but still some distance from where you'd get the best views. For anyone at latitude 40° north on the date of opposition, Jupiter's altitude at local midnight will be 50° above the southern horizon. In the Northern Hemisphere, for each degree of latitude south of 40° north an observer is, Jupiter will appear 1° higher; for each degree north of 40°, it will be 1° lower.

Crank up the power

Through a telescope, Jupiter shows more detail than any other celestial object except the Moon. Even a 2-inch scope will show the planet's four largest moons. The moons look like bright stars flanking Jupiter and can form some unusual arrangements.

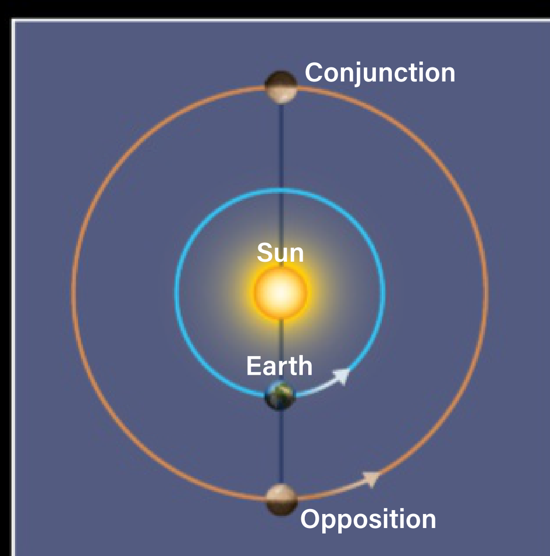
When you turn your gaze back to the planet, insert an eyepiece that provides a magnification around 100x, and the first details you'll notice will be a pair of dark stripes oriented parallel to the planet's equator. These stripes — one above and one below Jupiter's equator — are the North and South Equatorial Belts. Through larger telescopes and with higher magnifications, more belts and zones come into view. Planetary observers call the light-colored bands zones and the darker ones belts.

At magnifications above 250x, Jupiter appears squished, bulging at its sides. That's not an illusion. The planet's rapid rotation and the fact that it is not solid make its equatorial diameter 5,800 miles (9,300 kilometers) greater than its polar diameter.

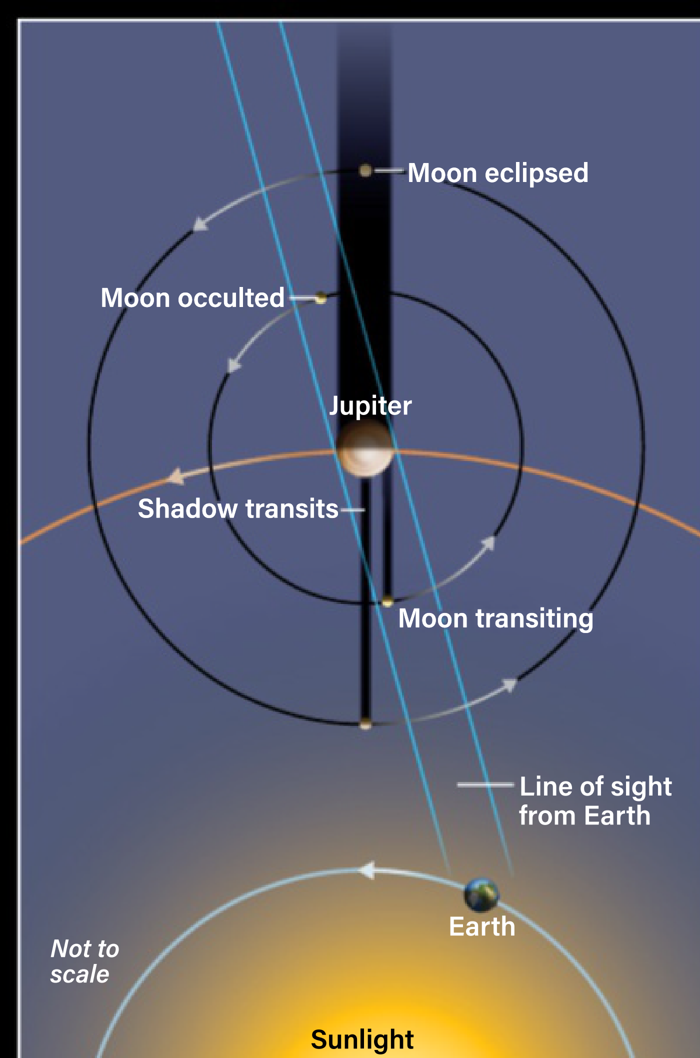
Rather than taking a quick look every now and then, try observing Jupiter over a series of nights. In addition to the changing positions of its moons, the planet's period of nine hours and 55½ minutes brings all of its visible area into view during a single night. Long-term observations may reveal individual features becoming more or less prominent and even disappearing for long stretches of time.

Spot the Spot

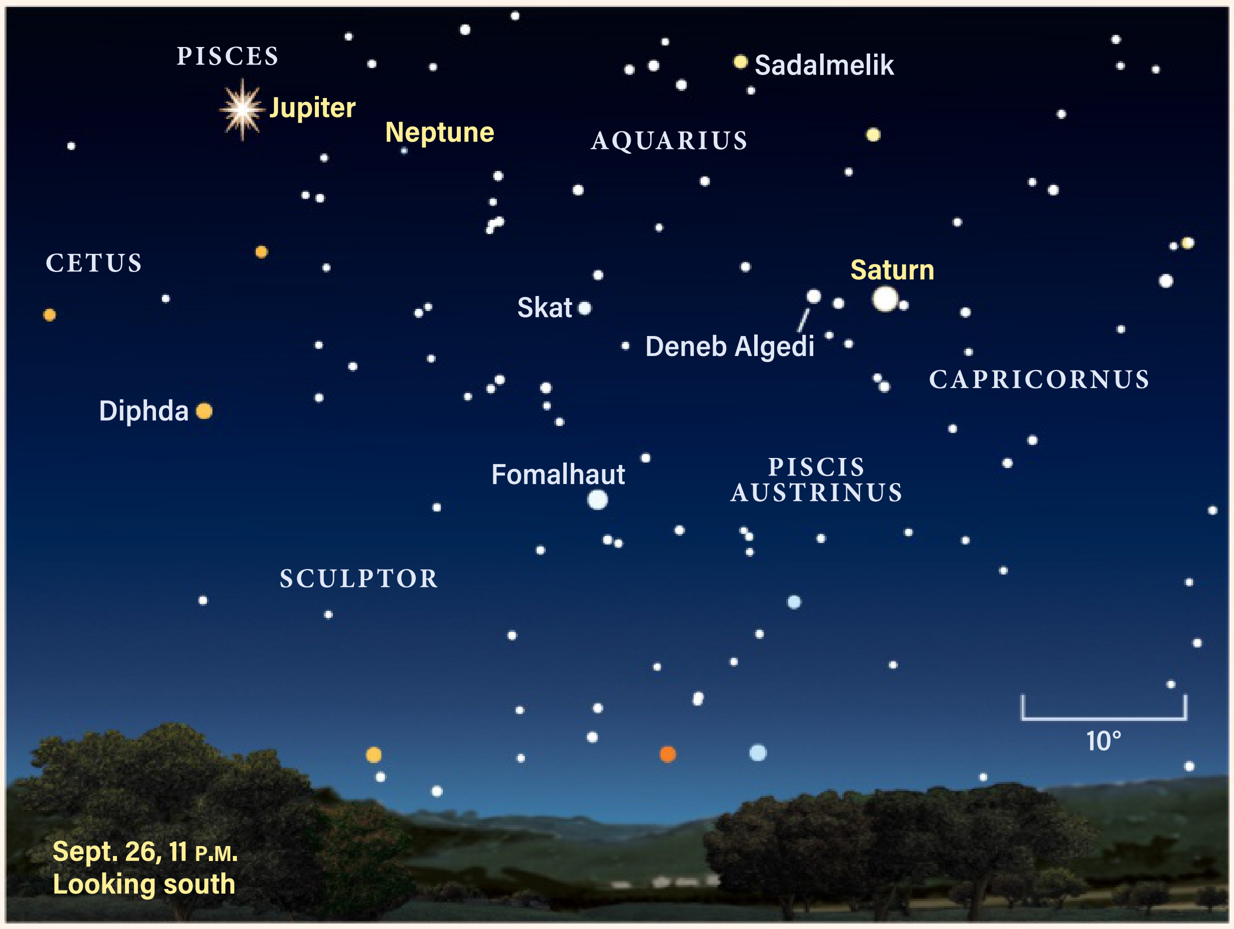
Jupiter's most famous atmospheric feature is the Great Red Spot (GRS), a high-pressure storm that lies 22° south of Jupiter's equator, drifting slowly through the South Equatorial Belt. You'll spot other similar features, but most are white and none are as large. The GRS has a north-south width of 8,700 miles (14,000 km) and a variable east-west width that was measured at some 25,000 miles (40,000 km) in the 1890s. The storm is slowly



ABOVE: Opposition occurs when a planet that orbits outside of Earth's orbit is positioned directly opposite the Sun. Around opposition is when a planet will be closest to Earth — prime time to observe it. *ASTRONOMY*: ROEN KELLY



RIGHT: In this diagram, Jupiter has not yet reached opposition, and the planet's shadow extends off to the west (right) as seen from Earth. Observers would be able to see the outer moon be eclipsed, emerge from eclipse, and then be occulted. However, the inner moon will be occulted before it emerges from eclipse. A moon and its shadow can transit the planet, though not necessarily at the same time. *ASTRONOMY*: ROEN KELLY



Jupiter reaches opposition Sept. 26 but will dominate its region of the sky for months. It spends the last half of 2022 in Pisces and Cetus, an area devoid of bright stars. *ASTRONOMY*: ROEN KELLY

JOVIAN FUN FACTS

- Jupiter's magnetosphere is the largest structure in the solar system. If it were visible from Earth, it would appear larger than the Full Moon.
- On a moonless night at a dark site, Jupiter can cast a visible shadow.
- At its equator, Jupiter rotates at 28,100 mph (45,300 km/h), more than 27 times as fast as Earth.
- If Jupiter were hollow, it could hold 1,320 Earths.
- On average, Jupiter travels 5' per day against the background stars. So, in a little over six days, the giant planet moves roughly the width of the Full Moon.
- The King of Planets is almost 318 times as massive as Earth.
- Jupiter reflects 34 percent of the sunlight that falls on it.
- The brightest planetary satellite visible from Earth (not counting the Moon) is Ganymede. At opposition, the solar system's largest moon glows at magnitude 4.4, a brightness that would make it visible to the naked eye if the glare from Jupiter didn't overwhelm it.

shrinking, however, and is currently just 10,000 miles (26,000 km) across.

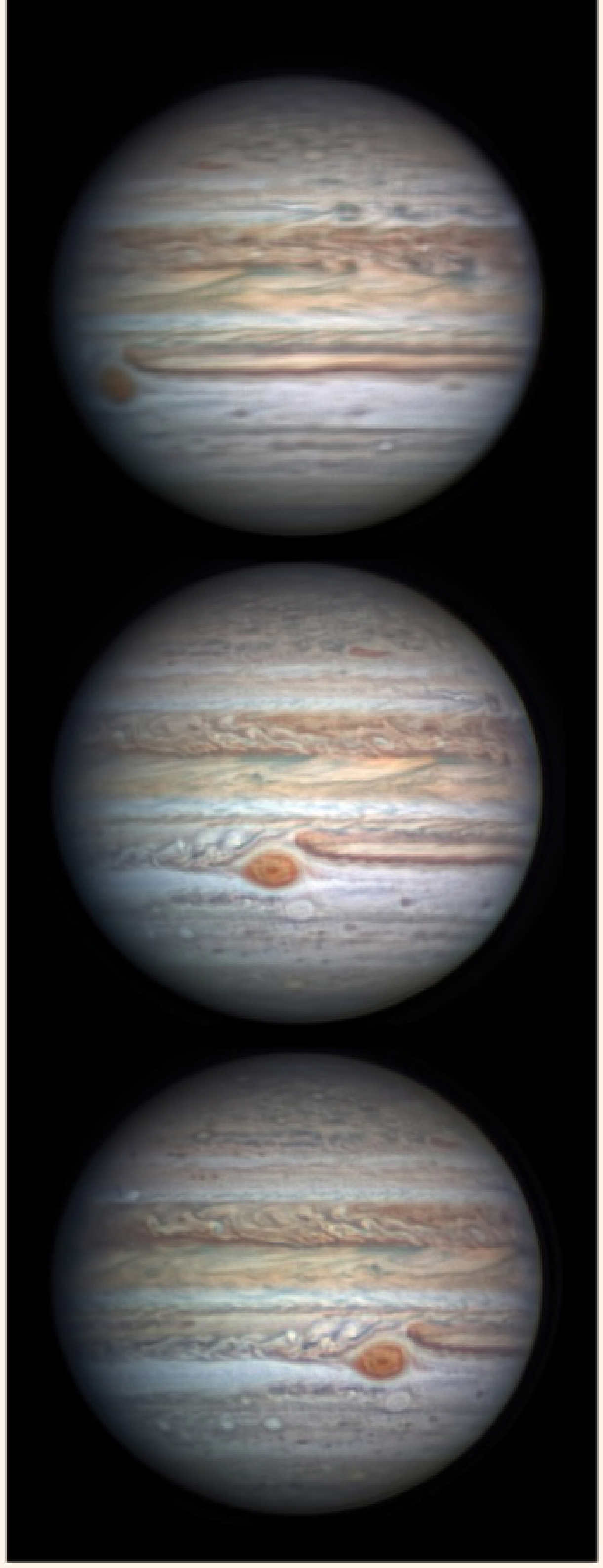
It also changes color because clouds at higher levels and of different compositions condense above it. The GRS has varied from brick red during the 1960s to pale pink in the 1990s. Since 2000, the spot's hue has remained light orange.

Moving moons

Jupiter's four largest moons are known as the Galilean satellites, named for their discoverer, Italian astronomer Galileo Galilei. On Jan. 7, 1610, Galileo saw three stars in a straight line, two on one side of Jupiter and one on the other. The next night, their positions had changed. Five nights later, he spotted a fourth star.

Galileo concluded that the "stars" were actually bodies revolving around Jupiter like the Moon circles Earth. His discovery made Io, Europa, Ganymede, and Callisto the first objects in the solar system to be observed despite being invisible to the naked eye.

The shadow of Ganymede falls across Jupiter in this image taken by NASA's Juno probe. The shadow seems especially large in this image because of how close to the planet Juno was — just 44,000 miles (71,000 km), or one-fifteenth the orbital distance of Ganymede. Swirling storm systems in the planet's belts and zones are also visible. IMAGE DATA: NASA/JPL-CALTECH/SWRI/MSSS. IMAGE PROCESSING BY THOMAS THOMOPOULOS © CC BY



Jupiter's Great Red Spot races through this set of images, taken at intervals of roughly one hour. Due to Jupiter's rapid rotation, you can observe the entire planet in one night. CHRISTOPHER GO

The ever-changing configuration of these moons can lead to four different types of observational events.

An *eclipse* occurs when a satellite moves through Jupiter's shadow, but is not positioned behind the planet from our point of view.

An *occultation* happens when a satellite passes behind Jupiter. These events occur along the planet's limb (edge). Eclipse events are easier to observe than occultations because eclipses usually take place some distance from Jupiter's limb. Moons always disappear into occultation at the west side of Jupiter and reappear at the planet's east side.

A *transit* occurs when a moon moves in front of the planet. A transiting satellite always moves from east to west across Jupiter's face. The satellites themselves look like bright dots against Jupiter's dark belts. When a satellite lies in front of the brighter zones, however, it's hard to see unless you follow it from the time the transit starts.

A *shadow transit* happens when a moon's shadow moves across Jupiter's disk. Shadows of the moons look like small black dots on Jupiter through any telescope. Transiting shadows also move from east to west across Jupiter.

Before opposition, from our perspective on Earth, Jupiter's shadow extends west of the planet, so a satellite will be eclipsed before it's occulted. The satellite being eclipsed gradually fades as it enters Jupiter's shadow, which is pretty cool to watch.

The two outer satellites, Ganymede and Callisto, are usually far enough from Jupiter to reappear from an eclipse, so you'll be able to see them disappear into occultation. However, Io and Europa emerge from their eclipses after their occultations start, so you won't see them reappear — they'll be behind the planet.

After opposition, when Jupiter's shadow falls east of the planet, occultations occur before eclipses. Then, you'll be able to see Io and Europa disappear into occultation and reappear from eclipse.

For transits and shadow transits before opposition, the satellite's shadow falls on the planet before the transit starts. After opposition, this order is reversed: The satellite begins its transit and the shadow follows.

Please note that any of these events can occur simultaneously among the four moons. For example, you might observe one or more satellites in transit across Jupiter, concurrent shadow transits, or multiple moons occulted by the planet.

If you have a 10-inch or larger scope and a night with great sky conditions, look for details on the moons. With high magnification (above 350x), you'll resolve their disks, especially during transits when the moons' glare drops because Jupiter's lit background provides less of a contrast than the black sky. Zoom in on Ganymede, the largest moon, first. Look for light-colored ice near its poles. Through bigger scopes, you might be able to see each satellite's (extremely) subtle color.

Less light, better view

The best advice I have for Jupiter observers is to use color filters to bring out details you won't see otherwise. And although they're called "color" filters, they produce non-color (grayscale) views. Their purpose is to enhance the contrast between features that are next to one another. Astronomical filters screw into the bottoms of eyepieces, which have matching threads. Like eyepieces, they come in two sizes, 1¼" and 2".

Manufacturers label filters by color and number. For better views of Jupiter's dark reddish-brown belts than you'd normally get, use a green (No. 58) or blue (No. 38A) filter. Blue also works best to sharpen any bright cloud features. A yellow (No. 12) filter will darken the planet's bluish features such as festoons, small regions that appear from time to time near the planet's equator.

Most observers use red (No. 23 or No. 25A) filters to enhance white spots and ovals in the South Temperate Belt and South Temperate Zone. Red filters also seem to work well on boosting the contrast of the northern and southern borders of the major belts.

Remember, filters don't make features brighter. Quite the opposite. So, when you use them you'll get better results through larger telescopes with eyepieces that provide medium to high magnifications. If you have a 6-inch or smaller telescope, use lighter filters. For example, use light red (No. 23A), light yellow (No. 8), or light blue (No. 82A) filters rather than their darker counterparts.

An audience with the king

As summer transforms to fall in the Northern Hemisphere, Jupiter provides a brilliant target for any observer, no matter your equipment. It's so bright, in fact, that you won't need to head to a dark site to view it. Set your scope up in your yard, pull up a chair, and carve out some time to see the giant planet at its best.

Michael E. Bakich *is a contributing editor of* Astronomy *who has observed lots (and lots) of Jupiter oppositions.*

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING

Mars observing season is heating up as the Red Planet approaches opposition in two months. Now is the time to perfect your observing technique. ALAN DYER

OCTOBER 2022
The planets get busy

Mars, Jupiter, and Saturn are October's major attractions. They offer stunning views at various times of night. In addition, Uranus and Mercury are occulted by the Moon, though both events are challenging observations. The month wraps up with a partial solar eclipse visible across Europe and the Middle East, while worldwide, the Orionid meteor shower occurs in good conditions.

Swing your telescope to eastern Capricornus for a fine view of **Saturn** each evening this month. It's visible at nightfall and doesn't set until nearly 3 A.M. in early October, and shortly before 1 A.M. at the end of the month. The ringed planet glows at magnitude 0.5, making it the brightest feature of Capricornus except when the Moon is around on Oct. 4 and 5. You'll find Saturn a pleasant 30° high in the southern sky during the first few hours of darkness.

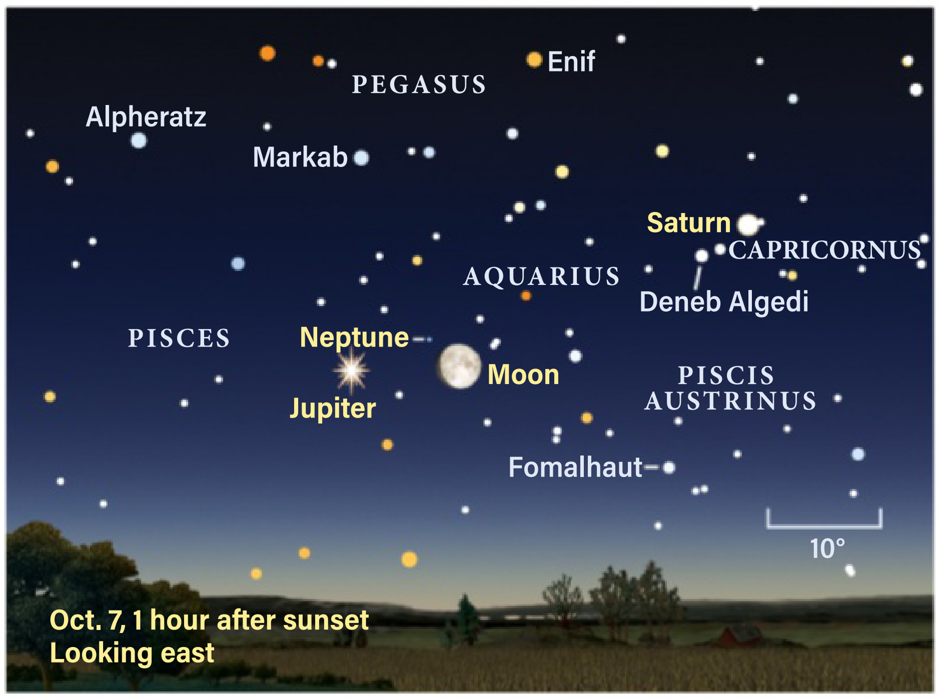
Saturn is elegant when viewed through a telescope at low magnification — set in a wealth of black sky, it resolves into a beautiful disk surrounded by its ring system. No one ever forgets their first view of this magnificent planet. The disk spans 18", with its polar diameter a smaller 16". As Earth pulls away from Saturn after August's opposition, the disk shrinks by about 3 percent this month.

The rings span 40" across their long axis, an overwhelming sight. Their apparent tilt to our line of sight is 15°, with their northern face sunlit.

Titan, Saturn's largest moon, shines at magnitude 8.5 — an easy target for small telescopes. You'll find it north of Saturn the mornings of Oct. 8 and 24, and due south Oct. 16. Fainter Tethys, Dione, and Rhea, all magnitude 10, change relative locations from night to night. Iapetus moves from an Oct. 4 inferior conjunction to reach western elongation Oct. 24, the day after Saturn reaches a stationary point on its retrograde loop. The evening of Oct. 3 in the U.S., you can spot this 11th-magnitude moon a mere 18" southeast of the planet. By late October, Iapetus' brighter hemisphere is facing us, increasing its magnitude to 10. You'll find it 8' due west of Saturn, with a trio of stars of similar magnitude to the moon's north.

You can easily find **Neptune** by using Jupiter as a guide. The ice giant starts the month about 9.5° west-southwest of the brighter planet. Neptune is a month past opposition and well placed nearly all night in eastern Aquarius, a few degrees south of the Circlet of Pisces. Binoculars will reveal it about 5.5° south of Lambda (λ) Piscium. A bright

Distant giants



Jupiter, Saturn, and Neptune (visible in binoculars) dominate the evening sky in October. On the 7th, the Moon stands due south of the solar system's most distant planet. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

OBSERVING HIGHLIGHT

THE MOON occults two planets this month: first **URANUS** on Oct. 11/12, then **MERCURY** on Oct. 24.

gibbous Moon lies 3° south of Neptune late on Oct. 7. Neptune glows at magnitude 7.7; a telescope reveals its dim bluish disk, spanning 2".

Jupiter is the brightest object in the evening sky aside from the Moon. It is visible all evening, shining at magnitude –2.9. It stands in southern Pisces, below the Square of Pegasus.

After opposition in late September, Jupiter maintains an apparent diameter of 50" for a few days into October, diminishing slightly to 48" by the end of the month. Early evening views are nice, and things only improve as Jupiter moves above 45° altitude around 11 P.M. local time in early October; this occurs progressively earlier as the month flows on.

Jupiter's dynamic atmosphere is its main attraction. Brownish belts straddle the equator and carry additional spots and festoons across the central median in minutes. Watch for the Great Red Spot's occasional appearance. Be patient and wait for fleeting moments of atmospheric stillness that offer the most incredible views of the gas giant.

The four Galilean moons — Io, Europa, Ganymede, and Callisto — orbit with periods of two to 16 days. Past opposition, the moons transit ahead of their shadows. A series of Europa

— Continued on page 38

RISING MOON | Look again

THAT YOU CAN EXPERIENCE the pleasure of the unexpected when you see it under a new light is an idea that applies nicely to lunar observing. Craters, scarps, and valleys take on a new face under a sunset illumination, compared with their traditional appearance when the Moon is waxing toward Full.

Later in the evening of the Oct. 14 (around 11 P.M.), a waning gibbous Luna is oddly unfamiliar. First to catch the eye along the terminator is the snaking Serpentine Ridge, its relationship to the entire Sea of Serenity now easy to see.

Jump halfway to the pole to the large and detailed crater Aristoteles. The low Sun angle transforms its apron of impact splatter into an expanse of roughness whose texture is as fine as the night and your telescope allow. The north-south shadow line down its middle sports a large scoop. Trace this light back to the small crater breaching the western flank that lets the Sun shine through.

Farther north and west, Protagoras lies sunken in the basin of Mare Frigoris, almost resembling the hole in a golf green. Typical craters in the region have raised rims and western-facing flanks brightly lit by the setting Sun. But here, the ancient lava flow came right up to the western lip of Protagoras. Under a waxing crescent's familiar lighting conditions on the evenings of the 1st and 31st, you might never suspect the unusual is hiding in plain sight.

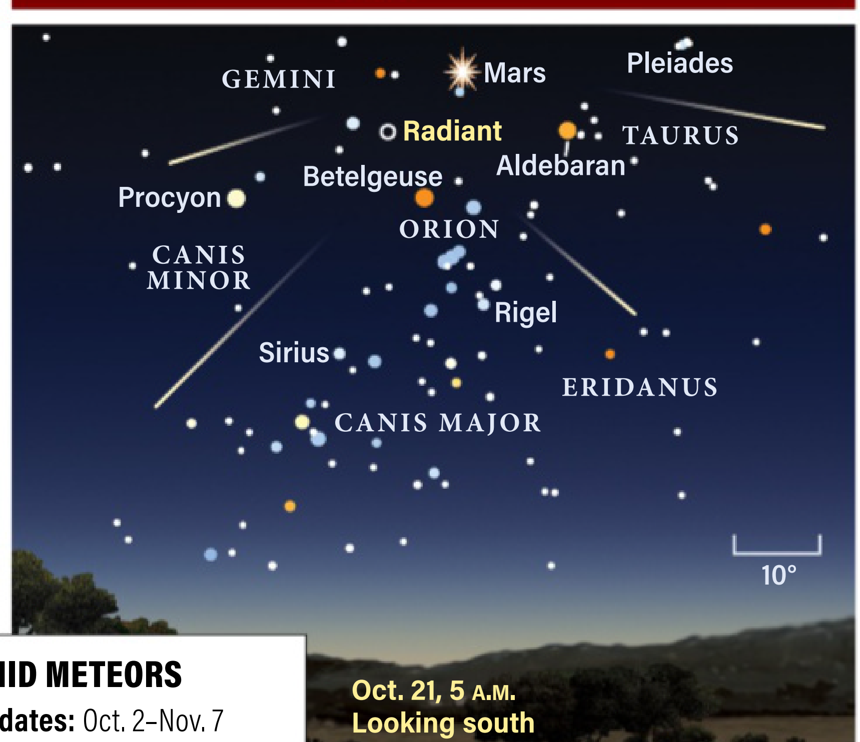
The shadows intensify on the 16th, with the Sun dropping down in the lunar sky. Nearby, the Alpine Valley (Vallis Alpes) cutting diagonally through rough terrain is a sight always worth the time. If the atmosphere is steady, pump up the power and look for the rille running down its middle. The valley rim will still be illuminated on the 17th for a post-midnight view.

Aristoteles, Protagoras, and Vallis Alpes

Familiar lunar features can appear new and strange in the reversed lighting of Last Quarter. CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

METEOR WATCH | A good show

Orionid meteor shower



The Orionids' radiant rises late in the evening and is well-placed for early morning viewing before dawn.

ORIONID METEORS

Active dates: Oct. 2–Nov. 7
Peak: Oct. 21
Moon at peak: Waning crescent
Maximum rate at peak: 20 meteors/hour

THE ORIONID METEOR SHOWER is active from Oct. 2 through Nov. 7, with the peak occurring the morning of Oct. 21. The radiant in northeastern Orion rises by 10:30 P.M. local time. A waning crescent Moon rises around 3 A.M. local time and is not a limiting factor this year. The shower has a consistent zenithal hourly rate of up to 20 meteors per hour at maximum, corresponding to an observable rate of 15 to 18 meteors per hour between 2 A.M. and dawn. Rates increase as morning hours progress.

The Orionids are a product of historic passes of Comet 1P/Halley through the inner solar system. Grab a hot chocolate, wrap up warmly, and settle onto a lounger to watch the winter constellations rise and wait for the glowing embers of Halley's dusty debris to momentarily brighten the sky.

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. October 1
9 P.M. October 15
8 P.M. October 31

Planets are shown at midmonth

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**

OCTOBER 2022

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1 Mercury is stationary, 11 A.M. EDT

2 First Quarter Moon occurs at 8:14 P.M. EDT

4 The Moon is at perigee (229,488 miles from Earth), 12:34 P.M. EDT

5 The Moon passes 4° south of Saturn, noon EDT

7 Asteroid Vesta is stationary, 2 A.M. EDT

The Moon passes 3° south of Neptune, 11 P.M. EDT

8 The Moon passes 2° south of Jupiter, 2 P.M. EDT

Pluto is stationary, 2 P.M. EDT

Mercury is at greatest western elongation (18°), 5 P.M. EDT

9 Full Moon occurs at 4:55 P.M. EDT

12 The Moon passes 0.8° north of Uranus, 3 A.M. EDT

15 The Moon passes 4° north of Mars, 1 A.M. EDT

17 The Moon is at apogee (251,238 miles from Earth), 6:20 A.M. EDT

Last Quarter Moon occurs at 1:15 P.M. EDT

18 Asteroid Juno is stationary, 8 P.M. EDT

21 Orionid meteor shower peaks

22 Venus is in superior conjunction, 5 P.M. EDT

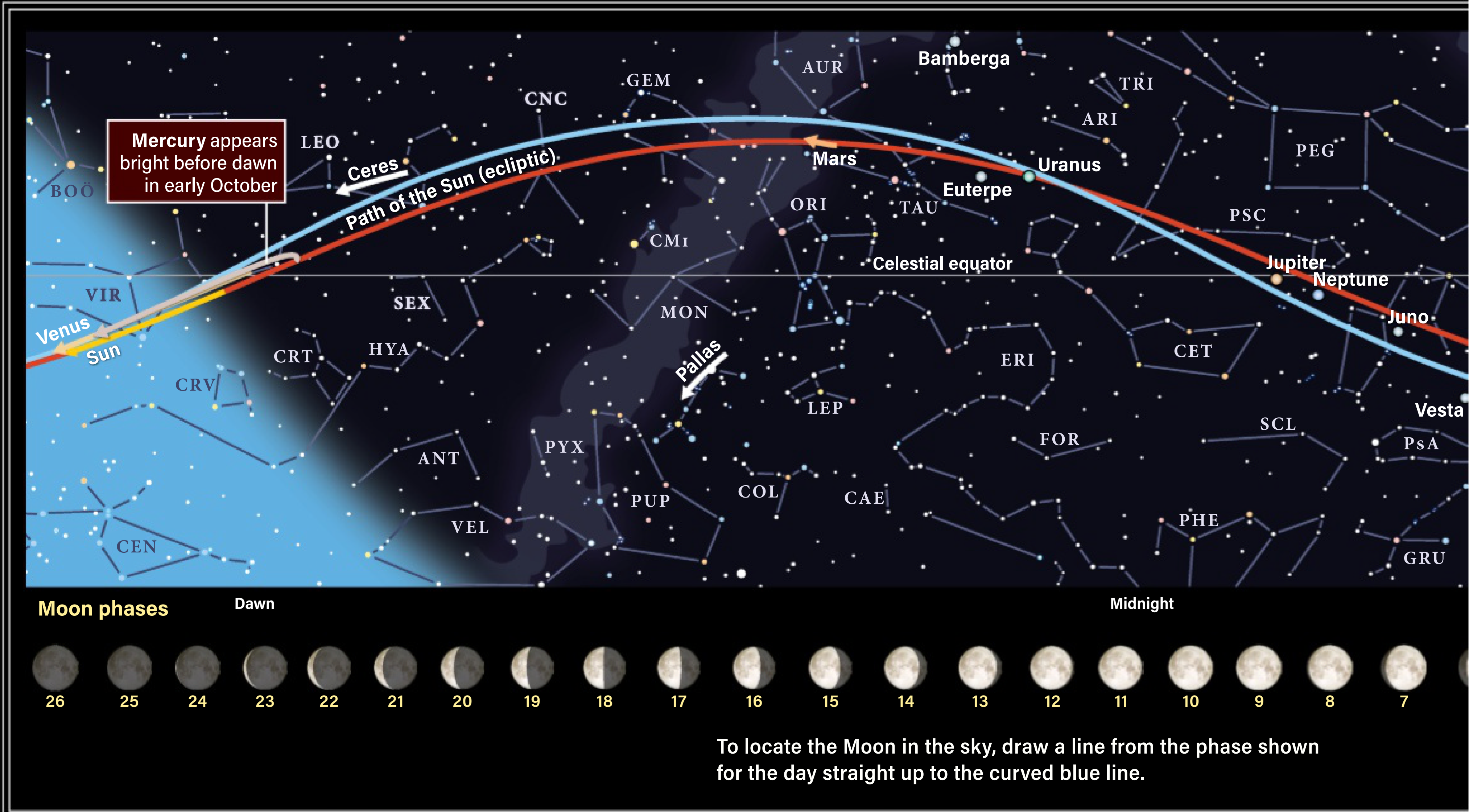
23 Saturn is stationary, 5 A.M. EDT

25 New Moon occurs at 6:49 A.M. EDT; partial solar eclipse

29 The Moon is at perigee (228,845 miles from Earth), 10:36 A.M. EDT

30 Mars is stationary, 7 A.M. EDT

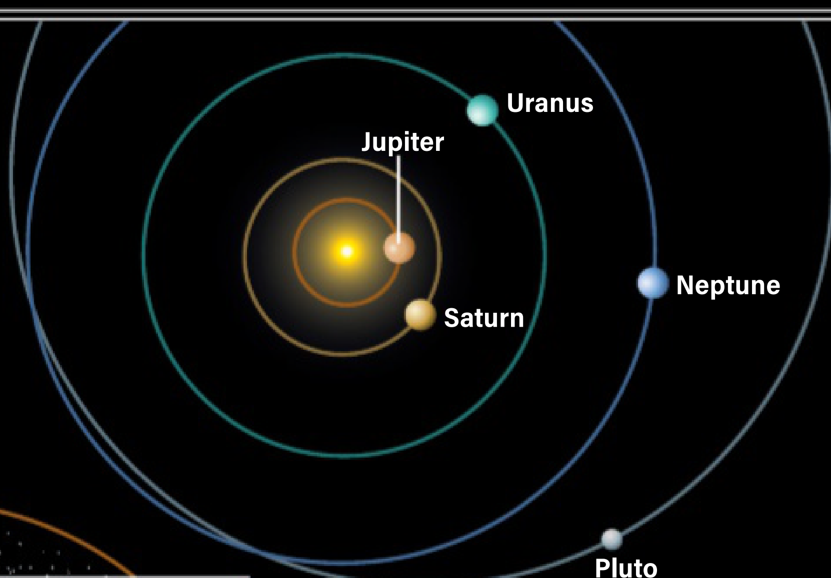
PATHS OF THE PLANETS

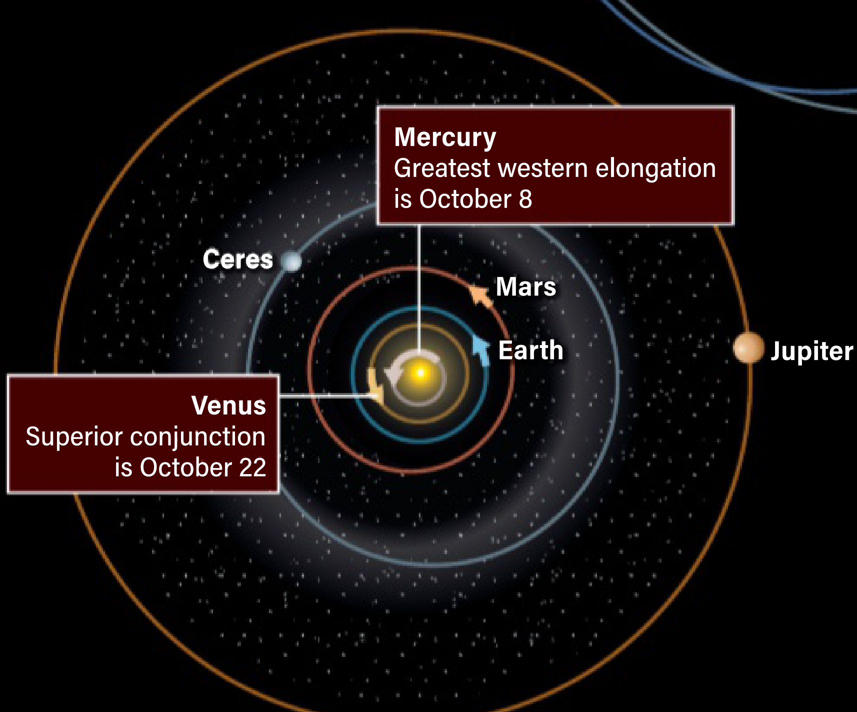


To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

THE PLANETS IN THEIR ORBITS

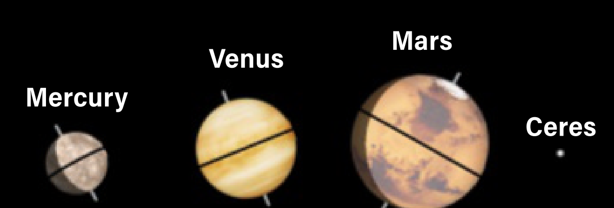
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.





THE PLANETS IN THE SKY

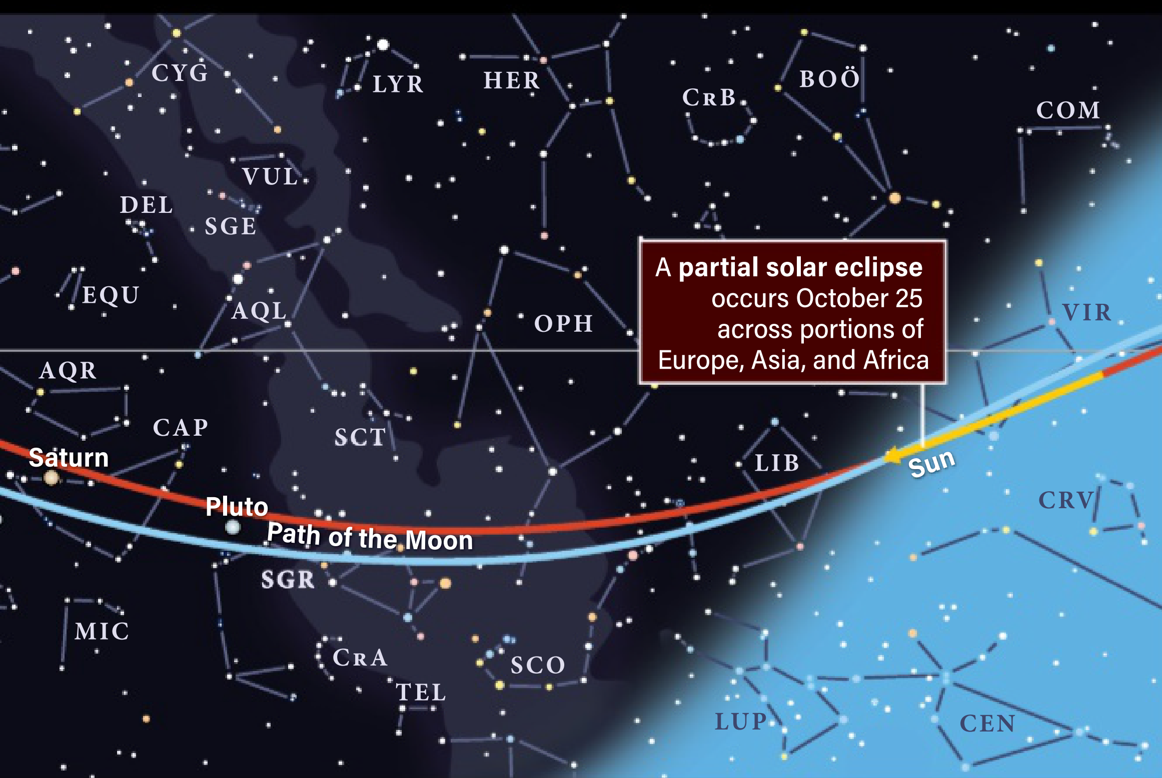
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



PLANETS	MERCURY	VENUS
Date	Oct. 15	Oct. 15
Magnitude	–0.9	–3.9
Angular size	6.0"	9.7"
Illumination	76%	100%
Distance (AU) from Earth	1.129	1.717
Distance (AU) from Sun	0.327	0.721
Right ascension (2000.0)	12h22.3m	13h13.0m
Declination (2000.0)	–0°15'	–6°24'

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

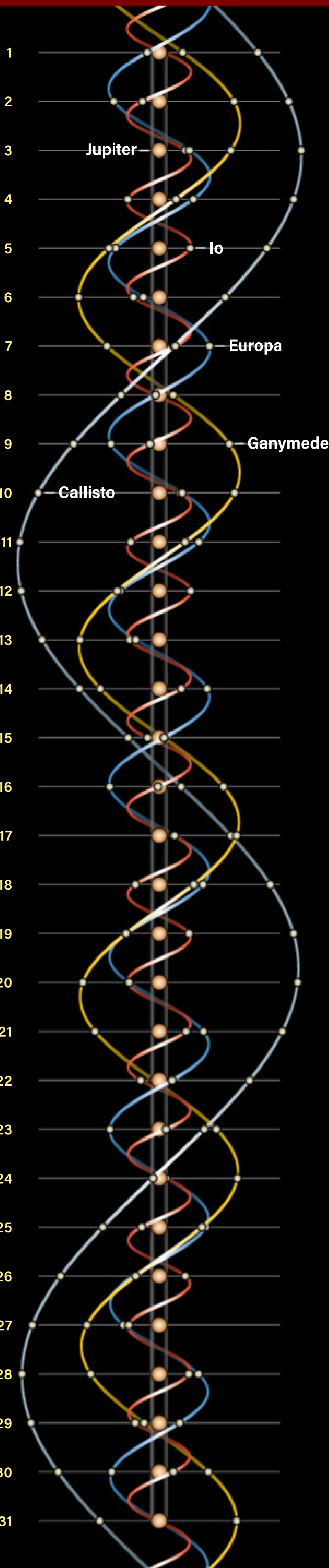
OCTOBER 2022



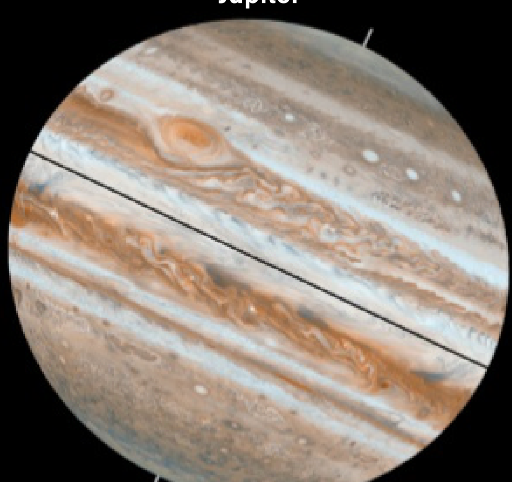
Early evening

JUPITER'S MOONS

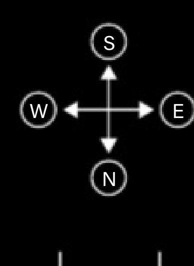
Dots display positions of Galilean satellites at 11 P.M. EDT on the date shown. South is at the top to match the view through a telescope.



Jupiter



Saturn



Uranus

Neptune

Pluto

MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15
–0.9	8.8	–2.9	0.5	5.7	7.7	15.2
13.3"	0.4"	49.2"	17.8"	3.8"	2.4"	0.1"
90%	98%	100%	100%	100%	100%	100%
0.705	3.153	4.006	9.362	18.782	29.033	34.533
1.464	2.554	4.954	9.855	19.681	29.914	34.625
5h32.4m	10h43.7m	0h06.4m	21h24.7m	3h01.0m	23h36.1m	19h53.0m
23°06'	16°05'	–1°03'	–16°35'	16°43'	–3°55'	–23°09'

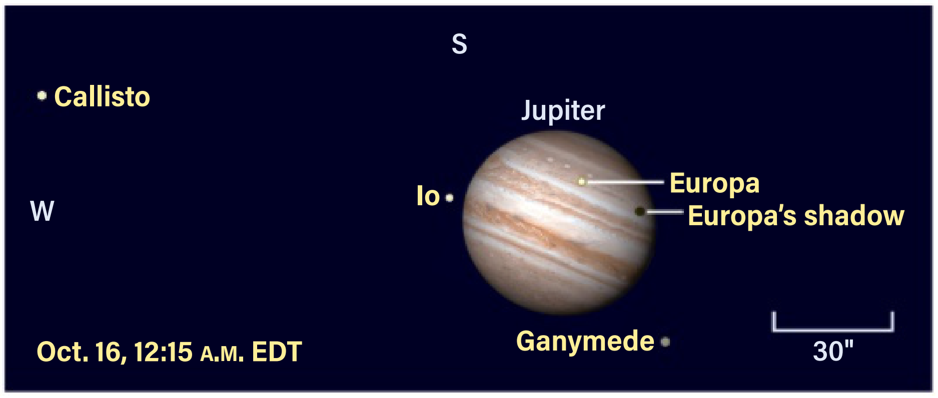
WHEN TO VIEW THE PLANETS

EVENING SKY
Jupiter (east)
Saturn (south)
Neptune (east)

MIDNIGHT
Mars (east)
Jupiter (south)
Saturn (southwest)
Uranus (east)
Neptune (south)

MORNING SKY
Mercury (east)
Mars (southwest)
Uranus (west)

Busy system



Catch Europa and its shadow transiting before Io disappears behind Jupiter early on Oct. 16 (late on Oct. 15 west of the Eastern time zone). Ganymede, dimmed by Jupiter's shadow, reappears just before 1 A.M. EDT.

transits followed by Io occultations occur Oct. 8, 15/16, and 22/23. Each of these is followed by an Io transit on the evenings of Oct. 9, 16, and 23.

On Oct. 8, Europa's transit begins at 8:49 P.M., its shadow begins to transit at 9:25 P.M., and Io disappears at 10:42 P.M. (all times EDT). On Oct. 15/16, events occur in the same order at 11:03 P.M., 12:01 A.M., and 12:26 A.M. (the last two events are on the 16th for those in the Eastern time zone only). On Oct. 23, events are in a slightly different order: Europa transits starting at 1:18 A.M., Io disappears at 2:11 A.M., and Europa's shadow slips onto the disk at 2:36 A.M. (Some or all events occur late on the 22nd in western time zones.) Also on the 22nd, Ganymede is occulted by Jupiter at 11:30 P.M. EDT.

Io and its shadow transit the day after each of the Europa events. These transits (moon, shadow) occur at 7:53 P.M. and 8:14 P.M. on the 9th, 9:38 P.M. and 10:09 P.M. on the 16th, and 11:24 P.M. (Oct. 23) and 12:05 A.M. (Oct. 24 for East Coast observers only; all times are again EDT). Note how the time between each moon and shadow transit stretches as October progresses — a feature of Earth's changing view of the Jupiter system relative to the direction of sunlight.

The next planet along the ecliptic, **Uranus**, is occulted by the Moon Oct. 11/12. Uranus currently lies in the sparse regions of southeastern Aries.

Those in the northwestern U.S. will see the occultation. Others will see a near miss, with Uranus south of the Moon. It's challenging to see magnitude 5.7 Uranus reappear near such a bright Moon, but there'll be lots of interest. The timing of the event is heavily location-dependent but occurs around 11:45 P.M. (For example, residents of Denver see Uranus appear at about 11:52 P.M. MDT on the 11th). Observers in the eastern U.S. will see a similar event on the first day of 2023.

Uranus is approaching next month's opposition. To find it, locate magnitude 2.5 Menkar in Cetus. Uranus stands about 12° due north of the star, slightly less than two field diameters in 7x50 binoculars. The aqua-colored planet is located between Sigma (σ) and 53 Arietis all month.

Through a telescope, try to discern the 4"-wide disk. At more than 1.7 billion miles from Earth, it's a marvelous sight. Use higher magnifications on nights of good seeing for the best views.

15" Mars grows from 12" to 15" this month. By December's opposition, it will span 17".

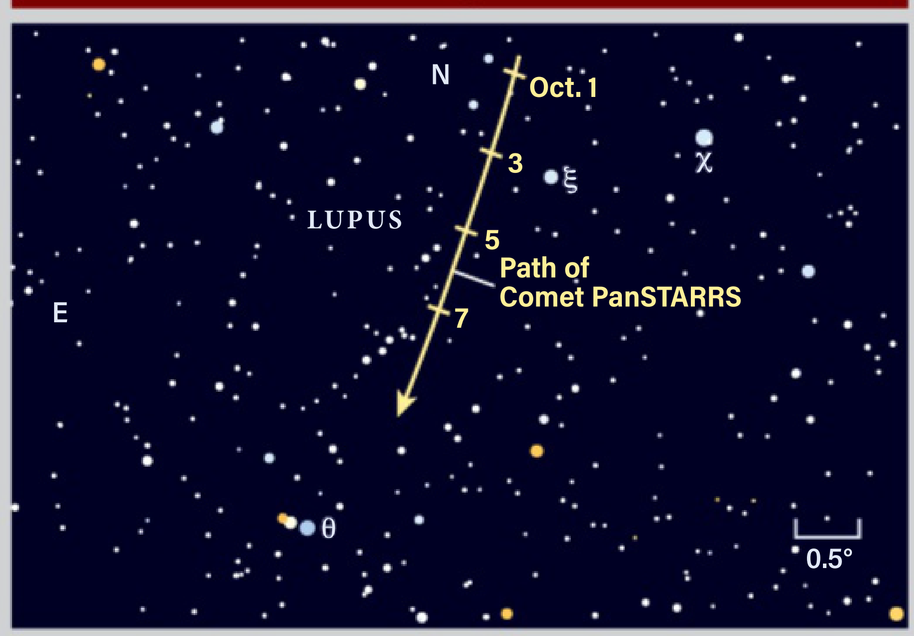
COMET SEARCH | The understudy takes over

"SEE YA NEXT YEAR!" is the thing to say to C/2017 K2 (PanSTARRS) as darkness falls on the first few nights of October, before the waxing Moon's light obscures it. You'll need a treeless southwestern horizon good enough to also see the False Comet asterism, spearheaded by NGC 6231 in the Scorpion's back. Thanks to Earth's curvature, PanSTARRS gains a few degrees of altitude for observers in the lower 48 states.

PanSTARRS should be sharpest to the south, with its soft, white dust tail fanning out to the east and north. Amazingly, the comet is still beyond the orbit of Mars and a couple of months before perihelion. Folks south of the equator now get a full year of it tickling naked-eye visibility. Gravity then loops the dirty snowball back north, treating us to a passage through Orion in December 2023.

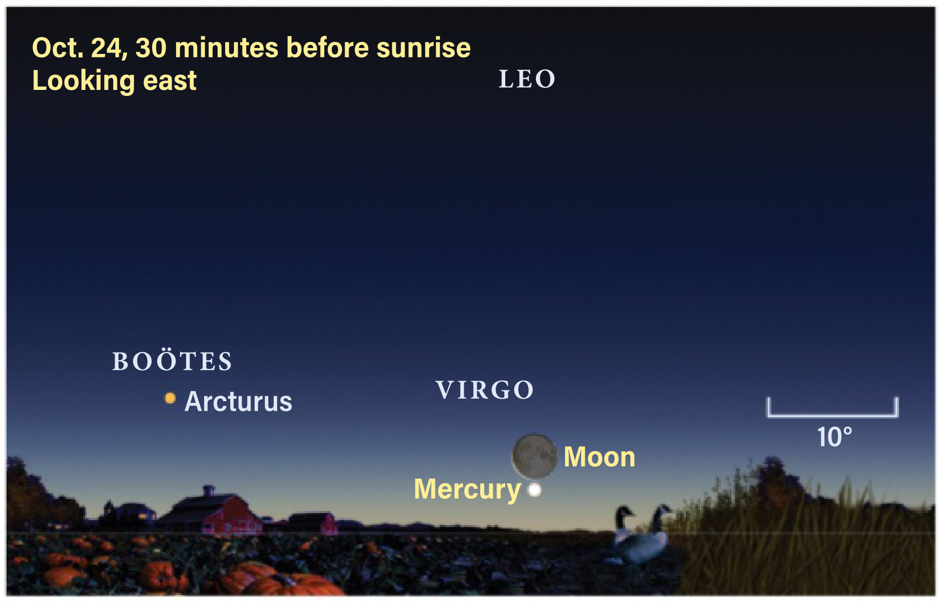
Fresh on the celestial stage, C/2022 E3 (ZTF) was discovered in March and is set to peak brighter than 6th magnitude in early 2023. For now, use an 8-inch scope under dark evening skies to pick out the 11th-magnitude puffball in Corona Borealis at the end of the month.

Comet C/2017 K2 (PanSTARRS)



Comet PanSTARRS is readily visible in the Northern Hemisphere only during early October. Visit our website to find observing charts for C/2022 E3 (ZTF) later in the month.

Pulling up close



The Moon and Mercury sit roughly 1° apart just before sunrise on Oct. 24. Later that morning, some will see the Moon occult Mercury.

Mars is a stunning object in the middle of Taurus on Oct. 1. It's now only two months from opposition as we enter the best time to observe the Red Planet. Mars rises around 10 P.M. and brightens from magnitude –0.6 to –1.1 during the month. It forms a stunning triangle with two bright red giant stars: Betelgeuse to its south and Aldebaran to its west.

The Moon joins Mars late on Oct. 14, separated by less than 4°. The Red Planet also stands within 1.1° of the Crab Nebula (M1) for about three days starting on this date, passing due north of the nebula on the 17th. The planet's eastward motion slows to a halt by Oct. 30, when it sits 2.7° north of Zeta (ζ) Tauri. It then begins a retrograde path.

Mars transits the local meridian around 5 A.M. This is the best time to view the planet or record high-speed video, and perfect your observing techniques. Its apparent diameter grows from 12" to 15" during the month, and its phase grows from 88 percent to 94 percent.

In the hours around local midnight, the following features face Earth (for Midwestern observers): Oct. 1: Olympus Mons; Oct. 5: Tharsis Ridge and Valles Marineris; Oct. 14: Solis Lacus; Oct. 22: Syrtis Major and the Hellas basin; Oct. 30: Mare Sirenum. Enjoy becoming familiar with these features as Mars approaches its early December opposition.

Mercury achieves its best morning apparition for Northern Hemisphere observers. It rises in the east 68 minutes before the Sun on Oct. 1 but is only magnitude 0.9. By Oct. 5, it brightens to magnitude 0. You'll find it a respectable 7° high 45 minutes before sunrise. It reaches greatest elongation (18°) on the 8th, now at magnitude –0.4. Mercury reaches magnitude –1 by Oct. 16, but two days later has fallen in altitude to 5° high 45 minutes before sunrise.

The planet continues to drop lower each morning. Can you spot Mercury Oct. 24, just over 1° southeast of the waning crescent Moon, one day prior to New Moon? The pair is only 4° high 30 minutes before sunrise in bright twilight — a challenge requiring very clear skies and a level eastern horizon. During daylight hours, the Moon occults Mercury soon after 10 A.M. EDT for U.S. observers. This is a challenging event because it is near the Sun (only 10° away). Significant safety precautions must be undertaken before making any attempts to view the occultation — do not randomly scan the sky looking for the Moon.

Venus is out of view, reaching superior conjunction Oct. 22. It reappears in the evening sky later in the year.

A partial solar eclipse occurs Oct. 25, visible across most of Europe, northeastern Africa, southwestern Asia, the Middle East, India, and portions of Russia. Observers in London experience the eclipse from 10:08 A.M. to 11:51 A.M. local time, with a maximum obscuration of 15 percent (26 percent of the Sun's diameter). Others across Europe experience a larger percentage of coverage and a longer duration.

***Martin Ratcliffe** is a planetarium professional with Evans & Sutherland and enjoys observing from Salt Lake City. **Alister Ling**, who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

LOCATING ASTEROIDS | Venerable Vesta

THIS IS A WONDERFUL TIME to spot your first (or hundredth) asteroid. From a suburban backyard or balcony, just point your binoculars one to two fields to the lower left of Saturn and tag the second-brightest dot.

Modestly well-placed in the southeastern sky mid-evening, 4 Vesta parades as a 7th-magnitude star. Use the parallelogram at the east end of Capricornus, anchored by magnitude 2.8 Delta (δ) Capricorni, to orient yourself. Then drop one field to the lower left. Make a sketch of the four brightest dots and return every few nights to pick out the one that moved. Globular cluster M30 is one field to the right — check it out if you're on the south side of town. It looks a bit fuzzy, just right of a magnitude 5.2 star.

The fourth main-belt asteroid to be discovered, Vesta spans more than 320 miles across and was intently examined by the Dawn spacecraft a decade ago. Heinrich Olbers spotted it in 1807 and might be amazed to know that astronomers have deduced that its oval body has a core, mantle, and crust.

Easy pickings

Seventh-magnitude Vesta is relatively simple to spot this month near Delta Capricorni, also called Deneb Algedi.

10 must-visit astro destinations

These museums, observatories, and telescopes should be on every enthusiast's travel list.

BY CAITLYN BUONGIORNO

With almost two years spent at home, travelers are eager to get a few more miles under their belts. But before you book your next trip, consider what else your destination has to offer, cosmologically speaking. Here are a few space-related destinations — in alphabetical order — that you should consider checking out the next time you travel.

Arcetri Astrophysical Observatory ▪ Florence, Italy

Atacama Desert ▪ Chile

Arcetri Astrophysical Observatory 1
Florence, Italy

Completed in 1872, the Arcetri Astrophysical Observatory was designed to house the largest refractor in Italy: the Amici telescope. With an 11-inch objective lens, the telescope retained its superlative status for 40 years.

German astronomer Wilhelm Tempel used the Amici telescope in his search for new nebulae, and his drawings are still on display at Arcetri. The original Amici telescope was upgraded twice. It now houses a 14-inch objective that is currently used for public outreach.

And today, research continues at the observatory, as scientists grapple with topics ranging from the study of minor bodies of the solar system to astrobiology.

Looking for more astronomical history in Florence? A half-hour walk from the observatory is the final residence of Galileo Galilei. The villa, referred to as Il Gioiello (The Jewel), is where Galileo served his life sentence (under house arrest) from 1633 until his death in 1642. His tomb, at the Basilica of Santa Croce, is also just a little over 2 miles (3.5 kilometers) from the observatory.

Atacama Desert 2
Chile

The Atacama Desert in Chile is an astronomer's paradise. Miles above sea level and free from major cities, the desert's arid weather and sparse rain make it perfect for stargazing — so much so that it is the premier location for professional telescopes. The majority of the European Southern Observatory's (ESO) telescopes are situated in the Atacama Desert, including the Very Large Telescope and the upcoming Extremely Large Telescope. This Chilean desert is also home to the Atacama Large Millimeter/submillimeter Array, better known as ALMA, the largest radio telescope in the world.

The Cerro Tololo Inter-American Observatory (CTIO) also resides here. CTIO is a complex of around 40 telescopes and instruments, including the 4.1-meter Southern Astrophysical Research (SOAR) Telescope and the Dark Energy Survey's Dark Energy Camera (DECam) on the Victor M. Blanco 4-meter Telescope. And while still under construction at the time of writing, the Vera C. Rubin Observatory (previously named the Large Synoptic Survey Telescope [LSST]) is scheduled to begin full science observations in December of next year.

LEFT TO RIGHT: Both the Amici telescope and the nebulae Wilhelm Tempel drew while using it are on display at the Arcetri Astrophysical Observatory. CELLAI STEFANO/DREAMSTIME

Once the Vera C. Rubin Observatory is completed, it promises to compile the largest astronomical catalog of universe. RUBIN OBSERVATORY/NSF/AURA

The Deutsches Museum (or the German Museum) is located on a small island in Munich, Germany. MARCO SPROVIERO, BEOBACHTERGRUPPE DEUTSCHES MUSEUM/DEUTSCHES MUSEUM

After touring these sites in the daytime, make sure you spend your nights scouring the desert skies — the best skies in the world — with your own telescope. Observers can spot all the great sights the Southern Hemisphere has to offer: the Magellanic Clouds, the Southern Cross, Proxima Centauri, and the Carina Nebula, just to name a few!

Deutsches Museum

Munich, Germany

3

From our solar system to the Big Bang, the Deutsches Museum in Munich, Germany, gives visitors an introductory course on the cosmos. Visitors can explore astronomy topics on floors 3 to 6 (remember that floor 0 is the ground floor in Europe). One floor hosts plenty of hands-on physics demonstrations for both kids and adults so they can better grasp the basic concepts that astrophysicists explore. The museum also has two observatories and a planetarium that are open for tours.

On top of all that, the museum is home to a wide range of telescopes and astronomical equipment, but the must-see attraction is Fraunhofer's Telescope. Astronomer J.G. Galle used this 9-inch (23 cm) scope in 1846 to discover Neptune.

Be aware that some observatories and telescopes require visitors to preregister online prior to visits.

Rose Center for Earth and Space

New York, New York

4

Part of the American Museum of Natural History, the Rose Center for Earth and Space is home to the Hayden Planetarium and a handful of permanent exhibits. Appearing to float within a glass cube, the top portion of the 87-foot (26 meters) Hayden Sphere houses the Hayden Planetarium Space Theater.

In the Hayden Big Bang Theater, visitors get to watch the birth of the cosmos — narrated by Liam Neeson — unfolding on a screen below their feet. Following a path spiraling out from the theater, visitors then walk through the history of the universe with the 360-foot-long (110 m) gallery, where one step is equal to a million years. The size of the sphere also serves as a handy visual scale when discussing celestial bodies, representing either the Sun or the Milky Way, depending on context.

The Hayden Planetarium Space Theater can seat 429 people and uses a scientifically accurate 3D map of the known universe as the foundation of the museum's Space Shows. Called the Digital Universe Atlas, this map uses millions of astronomical observations and is maintained by a team of experts to display a hyper realistic view of the universe.

Kennedy Space Center

Cape Canaveral, Florida

5

Cross two life achievements off your bucket list by visiting the Kennedy Space Center during a rocket launch. The Visitor Complex offers the closest possible public access to a launch, with viewing locations set up within a few miles of the launchpads. Countdowns and up-to-date information on the next rocket launch are available on their website at www.kennedyspacecenter.com.

Even if you can't book a trip during a launch (or, worst-case scenario, the launch gets rescheduled), there are plenty of other things to

BELOW (LEFT TO RIGHT): The Hayden Sphere takes up a majority of the Rose Center for Earth and Space and houses both the Hayden Big Bang Theater at its base and the Hayden Planetarium Space Theater at the top. Inside, the sphere acts as a visual scale for celestial bodies. D. FINNIN/© AMNH

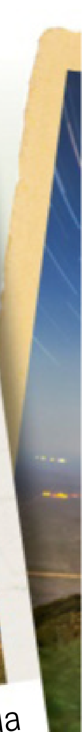
While at the Kennedy Space Center, visitors can walk through the Heroes and Legends exhibit, the Rocket Garden, and even take a tour of the restricted areas of NASA's space center. As an added bonus, you might even be able to witness a rocket launch — if you time your visit right. NASA/KIM SHIFLETT

Just 55 miles (89 km) outside of Tucson, Arizona, Kitt Peak National Observatory offers both daytime tours and nighttime observing sessions to visitors. KPNO/NOIRLAB/NSF/AURA/P. MARENFELD OR KPNO/NOIRLAB/NSF/AURA

Lowell Observatory is home to the 24-inch Clark Refractor, the 13-inch Lawrence Lowell Telescope, and the telescope that was used to discover Pluto in 1930. CLARKHARUN MEHMEDINOVIC/LOWELL OBSERVATORY

Rose Center for Earth and Space ▪ New York, New York

Kennedy Space Center ▪ Cape Canaveral, Florida



do at the complex, which is divided into several themed Mission Zones. Visitors can tour the history and future of space exploration by celebrating early pioneers and rockets with the Heroes and Legends exhibit, taking a guided bus tour of the restricted areas of NASA's space center, and getting a glimpse at the rockets that launched us to the stars.

6 Kitt Peak National Observatory

Pima County, Arizona

The Kitt Peak Observatory is a beacon of astronomical outreach for astronomers around the world, even making itself available to virtual visitors during peak pandemic times. When open to the public (double check online first), Kitt Peak has open hours during the daytime from 9 A.M. MST to 3:45 P.M. MST, during which you can tour the locations marked for visitors. Keep in mind that as a working research facility, it does include some buildings that are barred to the public.

The observatory also offers nighttime programs, provided visitors have registered in advance. Guests can choose from three programs that guide visitors through observing the night sky. An overnight observing program is also available, which places guests in the shoes of an astronomer. You will be given a dorm room, have dinner in the cafeteria with astronomers and staff, and be slotted in for telescope time.

A few honorable mentions

Griffith Observatory

Los Angeles, California

Free to the public, Griffith Observatory overlooks Los Angeles atop Mount Hollywood in Griffith Park. Offering visitors an introduction to astronomy and telescopes (despite its light-polluted skies), the observatory also boasts the best views of the famed Hollywood sign.

National Air and Space Museum

Washington, D.C.

Temporarily closed through fall 2022, the National Air and Space Museum is approaching the finish line of a seven-year renovation. By 2025, the museum plans to have reimagined its 23 exhibits and added over 1,400 new objects to its collection.

Royal Observatory

Greenwich, U.K.

Known as the Home of Time, the Royal Observatory sits on the Prime Meridian (longitude 0°0′0″), marking the divide between the Western and Eastern hemispheres of the globe.

Teide National Park

Canary Islands, Spain

A UNESCO World Heritage site, Teide National Park has served as a testbed for the European Space Agency's model rovers, thanks to its lunarlike environment.

Very Large Array

Socorro, New Mexico

Closed to the public at the time of writing, the Very Large Array (VLA) in New Mexico is normally open for self-guided tours. This walking circuit culminates with guests standing at the base of one of the 230-ton VLA antennas!

7 Lowell Observatory

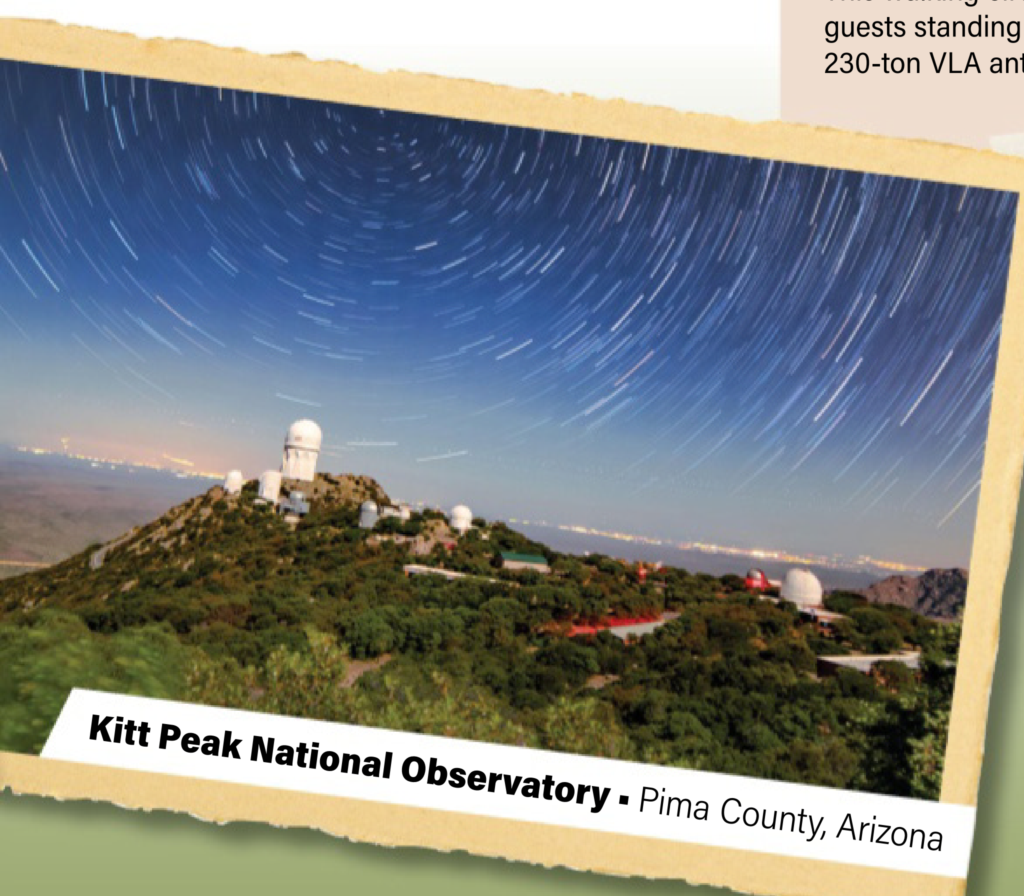
Flagstaff, Arizona

Taking advantage of the near-pristine skies Arizona has to offer, Lowell Observatory also gives visitors a chance to do some solar and nighttime observing. But this site is on our list because of the historical telescopes it has on display.

Lowell Observatory is home to two historic telescopes: The 24-inch Clark Refractor and the 13-inch Lawrence Lowell Telescope. Percival Lowell developed his controversial views of intelligent martian life while looking through the 24-inch Clark Refractor. The telescope was later used by Vesto M. Slipher to determine that distant galaxies are moving away from us.

Visitors can also visit the site where Clyde Tombaugh discovered Pluto. Nicknamed the Pluto Discovery Dome, the 13-inch Lawrence Lowell Telescope was used by Tombaugh in 1930 to discover the ninth planet in our solar system. (Later, in 2006, Pluto was reclassified as a dwarf planet — a decision marred by controversy.)

The Giovale Open Deck Observatory is like a candy shop for telescope enthusiasts and amateur astronomers. The plaza features six advanced telescopes for observers to look through. The 24-inch Dyer Telescope is the latest addition to the observatory, installed in 2020. Visitors can purchase a private observing session with the telescope separately from general admission.



Kitt Peak National Observatory ▪ Pima County, Arizona

Lowell Observatory ▪ Flagstaff, Arizona

Dome Theater ▪ Milwaukee, Wisconsin

Shanghai Planetarium
Shanghai, China 8

The world's largest astronomy museum, the Shanghai Planetarium is part of the Shanghai Science & Technology Museum. The planetarium's overall design is inspired by the orbital motion of celestial bodies, while the three rounded shapes atop the planetarium are meant to represent the Sun, Moon, and stars.

Above the main entrance to the museum is the Oculus, where unimpeded sunlight streams through a circular skylight, marking the passage of time like a sundial. On the right side of the building is the planetarium theater, which is housed in a sphere with minimal visible support. The effect is meant to invoke the illusion of weightlessness. And finally, a visitor's experience culminates at an inverted dome offering a view of the sky — a real encounter with the universe after a mostly simulated experience.

Permanent exhibits include a walk-through of the history of the universe, human exploration, and China's astronomical records; an interactive "Journey to Mars" virtual reality experience; and a 78-foot (24 m) solar telescope.

ABOVE: The Daniel M. Soref Dome Theater and Planetarium is *Astronomy*'s local destintation. TONY SAVINO/DREAMSTIME

BELOW LEFT: The Shanghai Science & Technology Museum's Shanghai Planetarium is the largest astronomy museum in the world. ARCH-EXIST

BELOW RIGHT: The South African Astronomical Observatory's Sutherland facility is home to the South African Large Telescope (SALT), the 1.0-meter and 1.9-meter telescopes, and the Lesedi 1-meter telescope. SAAO/JANIK ALHEIT

South African Astronomical Observatory 9
Cape Town, South Africa

Founded in 1820, the South African Astronomical Observatory (SAAO) is the national center for optical and infrared astronomy. Cape Town hosts the observatory's headquarters, while several working telescopes are in the Karoo region at SAAO's Sutherland facility.

The headquarters at Cape Town is recognized as a National Heritage Site and is accessible to visitors on Open Nights, which occur every second and fourth Sunday of the month. Guests can view a presentation on physics or astronomy, tour the museum and library, and observe through the McClean Telescope on clear nights.

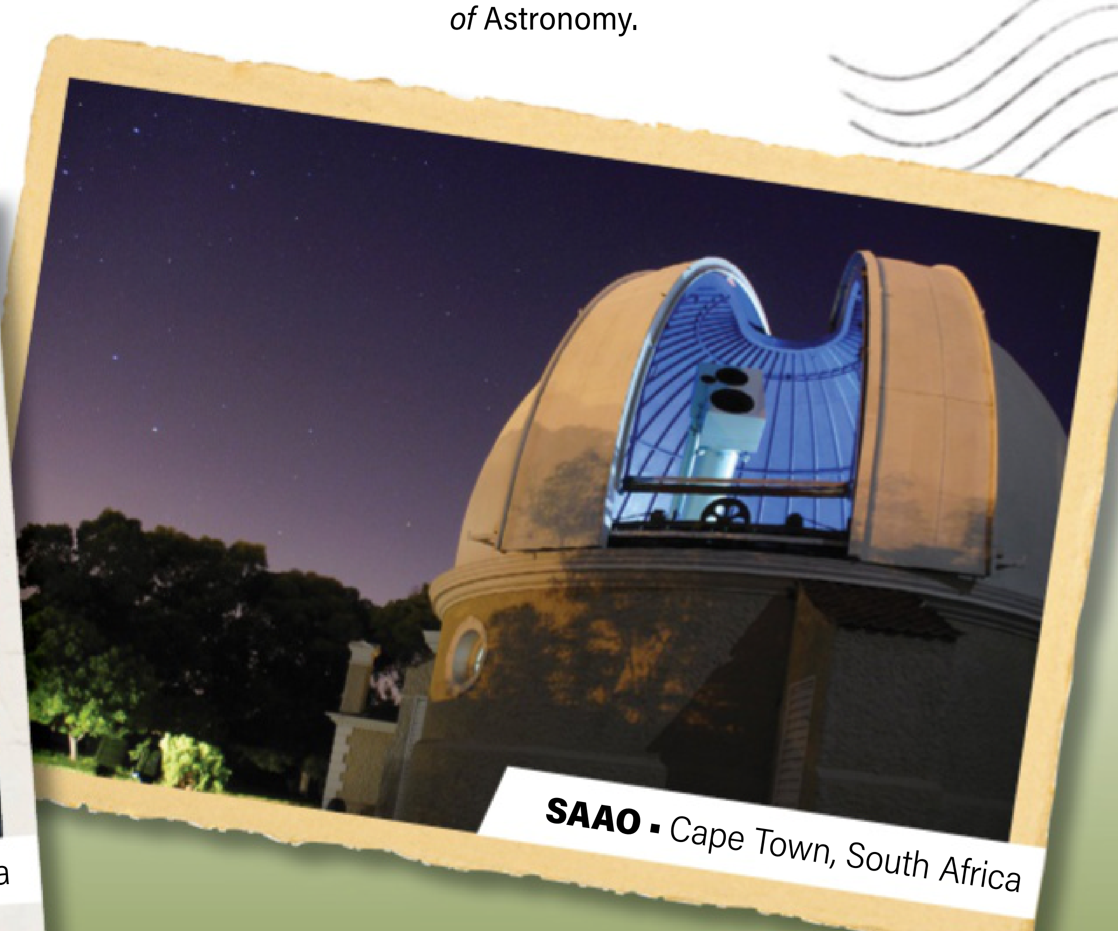
With some of the best skies the world has to offer, the Sutherland site hosts the Southern African Large Telescope (SALT), the 1.0-meter and 1.9-meter telescopes, and the Lesedi 1-meter telescope. (*Lesedi* means "light" or "enlightenment" in Sesotho, one of the official languages in South Africa.) Daytime and nighttime fully guided tours of the Sutherland site are available.

Your local space museum or planetarium 10

Can't make it far from home? That's okay! Check nearby cities for astronomical exhibits or planetariums to enjoy. And, if all else fails, you always have access to the real deal just above your head!

Caitlyn Buongiorno *is associate editor of* Astronomy.

Shanghai Planetarium ▪ Shanghai, China

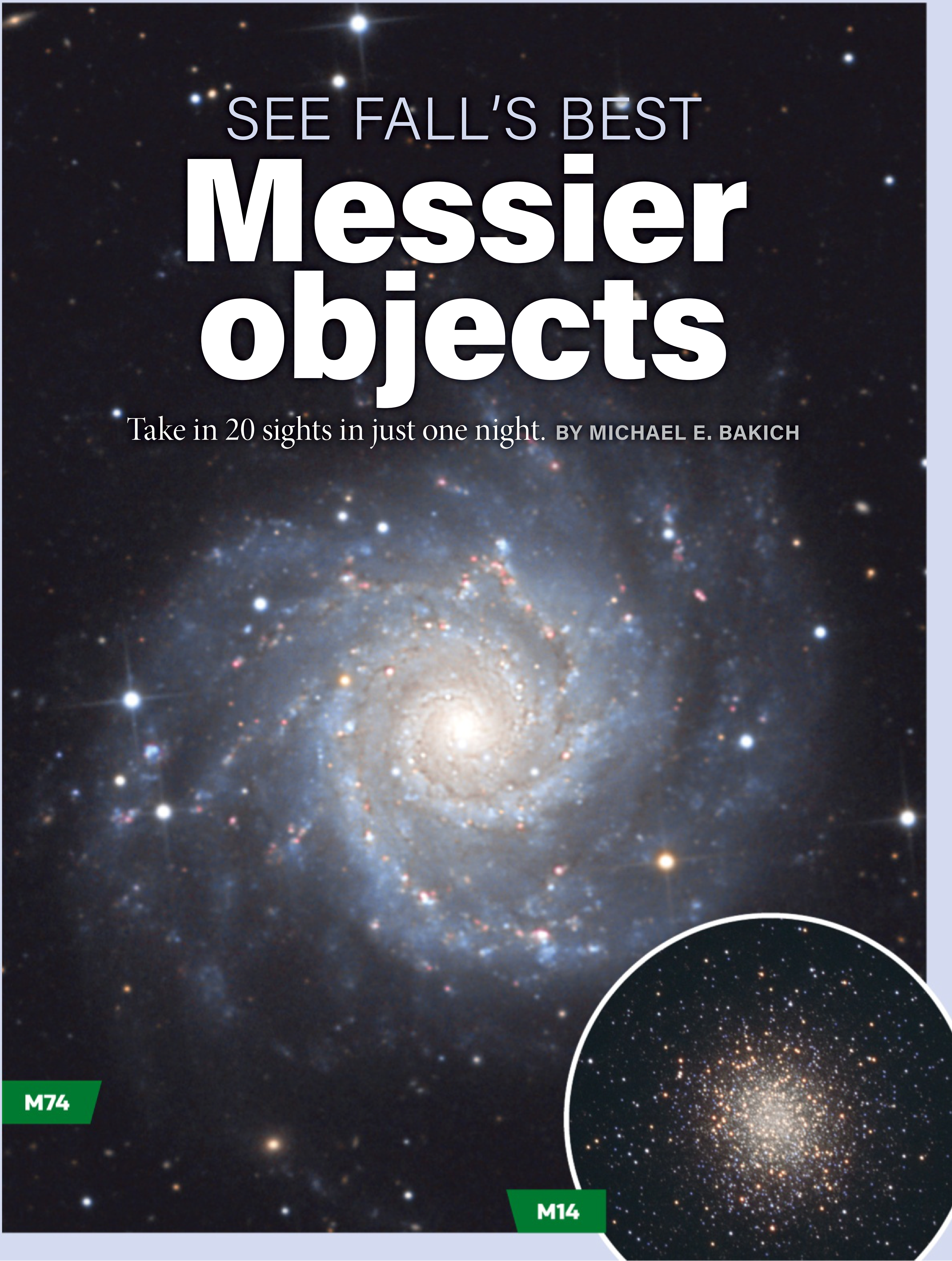


SAAO ▪ Cape Town, South Africa

SEE FALL'S BEST

Messier objects

Take in 20 sights in just one night. BY MICHAEL E. BAKICH



M74: SERGEY TRUDOLYUBOV. M14: FERNANDO OLIVEIRA DE MENEZES

M21

M28

It's been six months since astronomy clubs around the globe hosted events for the Messier marathon. The goal of this single-night observing challenge is to catch all 109 deep-sky objects in French comet-hunter Charles Messier's famous catalog.

Due to the way these celestial gems are positioned in the sky, there is only a brief span from mid-March to early April when all the objects are visible over the course of a single night. But even if you missed the last full marathon experience, you can keep your observational muscles in shape by giving this mini-marathon a try.

In the spirit of my mini-Messier marathons for spring (April 2021 issue) and summer (August 2021 issue), here is your agenda for autumn. And, unlike participating in a full Messier marathon, you won't have to stay up all night for this one; you can view all 20 of these objects between the time it gets dark and midnight.

I've listed the objects in order of right ascension, which means the first will be farthest west and the following objects will set in order after it, giving you more time to observe each.

In 2022, the Moon is New on Sept. 25 and Oct. 25. So, your first observing window runs from around Sept. 18 to Sept. 27. Starting Sept. 28, stray moonlight will interfere with your search until Last Quarter, which occurs on Oct. 17. Then the sky will stay Moon-free until past midnight for another week, marking your second observing window. Be sure to let your scope cool to the ambient temperature, take your time with each object, and have fun!

Let's get started

Our first target is globular cluster **M14** in Ophiuchus, which is neither faint (magnitude 7.6) nor small (11.7'). However, it lies in a part of the sky far from any bright star. To find it, start at Gamma (γ) Ophiuchi and move 6.5° south-southwest. Through a 4-inch scope at 100x, you'll see a tight sphere that's not easy to resolve. Then crank up the power and see if you notice that it's not perfectly round; it appears slightly stretched in an east-west orientation.

Next, look for open cluster **M21** in Sagittarius. It glows at magnitude 5.9 and spans 13'. You'll find this often overlooked Messier object 2.6° southwest of Mu (μ) Sagittarii. You'll definitely spot the Trifid Nebula (M20) first. When you do, look slightly northeast for M21. A 6-inch scope reveals two dozen stars brighter than 12th magnitude. The 7.2-magnitude star SAO 186215 shines at the cluster's center.

The third object on our list, **M24**, also known as the Small Sagittarius Star Cloud, is an asterism. Start by finding it through binoculars 3° north of Mu Sagittarii. At magnitude 4.6, it's relatively bright, and it measures a whopping 95' by 35'. At M24's northwest end is NGC 6603, a magnificent open cluster of several dozen stars. And while you're in the area, look 1° west-northwest for Barnard 92, a dark nebula shaped like a fingerprint.

M28: FERNANDO OLIVEIRA DE MENEZES. M21: DAN CROWSON. M29: RICHARD HAMMAR. M31: DREW EVANS. M39: SARA KHALAFINEJAD. M72: DAN CROWSON

M29

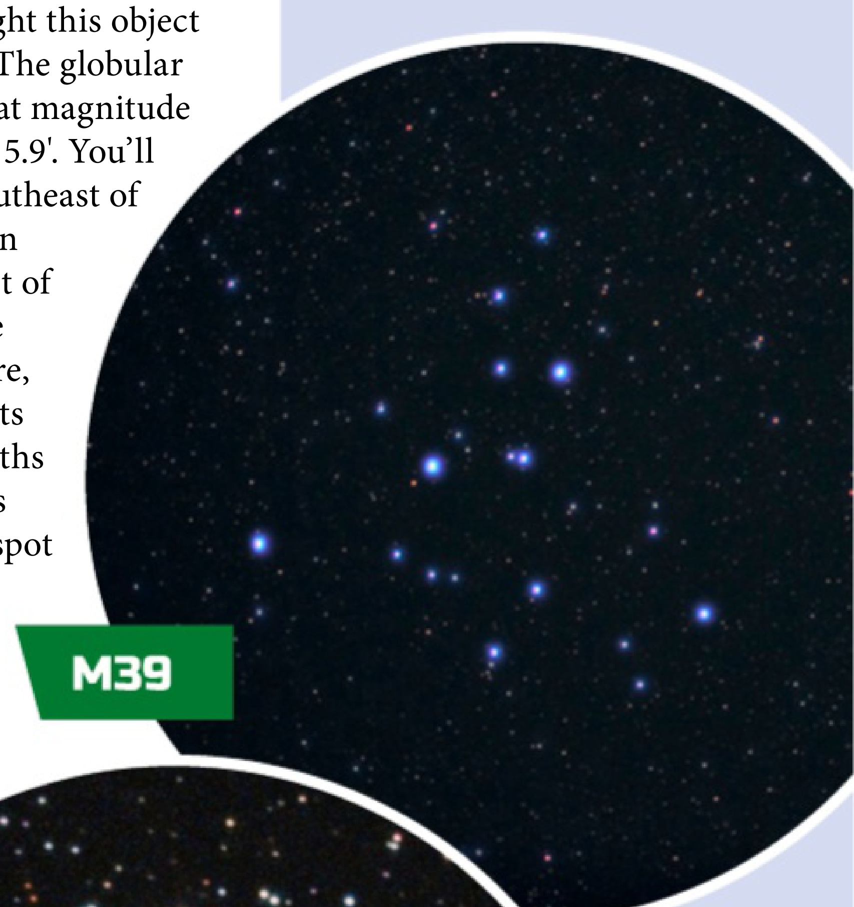
The 6.9-magnitude open cluster **M18**, which you'll find 4.2° north-northeast of Mu Sagittarii, is up next. A 4-inch telescope reveals about a dozen stars in a region 10' across. Take it easy on the power — higher magnifications spread the cluster out so much that it gets lost among the background stars.

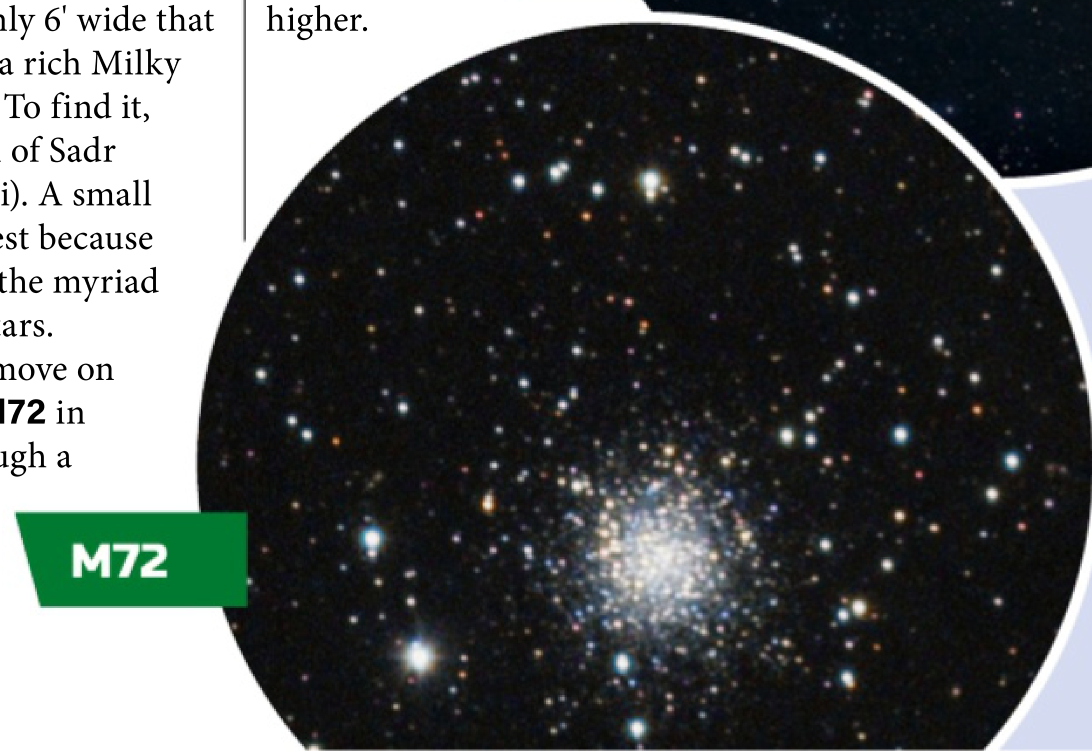
Our second globular on the list (often ignored because spectacular M22 resides nearby) is **M28** in Sagittarius. It glows at magnitude 6.8 and boasts a diameter of 11.2'. Look for it 1° northwest of Lambda (λ) Sagittarii. An 8-inch scope will resolve several dozen stars in its wide halo. Through a 14-inch scope, your star count will climb to more than 150. High-power views of the core unlock its three-dimensional appearance.

Next, look 2.5° northeast of Kaus Australis (Epsilon [ε] Sagittarii) for another globular, magnitude 7.6 **M69**. Through an 8-inch scope, you'll have to look carefully to resolve any of the stars packed in its 9.8' diameter. Its core appears broad but concentrated, and it is surrounded by a thin halo. M69 lies in a rich star field, so crank up the power to see it best.

Our next target, **M29**, lies in Cygnus. Although it's relatively bright (magnitude 6.6), it's one of the most difficult objects on Messier's list to identify because it's a loose open cluster only 6' wide that sits in front of a rich Milky Way star field. To find it, look 1.8° south of Sadr (Gamma Cygni). A small scope works best because it won't reveal the myriad surrounding stars.

When you move on to observing **M72** in Aquarius through a small scope, you can see why Messier initially thought this object was a comet. The globular cluster glows at magnitude 9.3 and spans 5.9'. You'll find it 3.3° southeast of Albali (Epsilon Aquarii). Most of M72's stars lie close to its core, which accounts for three-fourths of the cluster's diameter. To spot the outliers, use a magnification of 200x or higher.





Also located in Aquarius, **M73** resides just 1.2° east of M72. With a magnitude of 8.9 and angular diameter of just 2.8', M73 is nothing more than an equilateral triangle of stars with a fourth star lying just to the north-northwest. That Messier thought that this pedestrian grouping could be confused for a comet proves how primitive his telescope was. It's all right to take a quick glance and check this object off your list.

Now head north and find open cluster **M39** in Cygnus. It glows at magnitude 4.6 and sports a diameter of 0.5°. To locate it, point your telescope 2.8° north-northeast of Rho (ρ) Cygni. Look closely through a low-power eyepiece. M39 is so big that it's easy to lose among the rich Milky Way background. You should be able to count two dozen stars brighter than 12th magnitude.

Move to Cassiopeia for our next target, open cluster **M52**. Find it by tracing a line from magnitude 2.2 Alpha (α) Cassiopeiae to magnitude 2.3 Beta (β) Cas. The distance between those stars is 5°. Continue another 6° and you'll land on M52. An 8-inch scope will reveal this magnitude 6.9 cluster to have some 75 stars ranging from 9th to 12th magnitude packed within about 13' across. Although there are lots of stars in the field, M52 is easy to spot. Look for the prominent clump of six stars on its eastern edge.

Next up is the magnificent spiral **M31**, also known as the Andromeda Galaxy, along with its satellite, elliptical galaxy **M32**. The latter object glows at magnitude 8.1 and lies 0.4° south of the center of M31. But at 8' by 6', M32 is not the standout in this part of the sky.

M31 glows at magnitude 3.4, bright enough to spot from a dark sky without optics. It's also huge, measuring 185' by 75', an area greater than a dozen Full Moons. This star city is the nearest large spiral to our Milky Way, and it sits at the far end of the Local Group of galaxies. To observe it, either use low power for an overall view, which includes M31's nucleus, dust lanes, and two companion galaxies (M32 and NGC 205), or crank up the power and take in small regions at a time. Especially look for bright clumps in M31's spiral arms that mark sites where new stars are forming.

Neighboring Cassiopeia holds our next target, **M103**. This magnitude 7.4 open cluster lies 1° northeast of Delta (δ) Cassiopeiae. M103's bright stars stand out against the rich Milky Way. The 40 members range from 8th to 13th magnitude and are grouped in a tight triangle 5' on a side.

The compact trio of stars that make up the constellation Triangulum holds one of the sky's true wonders: **M33**, also known as the Pinwheel Galaxy (not to be confused with M101, also often called the Pinwheel Galaxy). This magnificent spiral glows at magnitude 5.7 and measures 67' by 42'. Despite its listed magnitude, this galaxy has a low surface brightness. Binoculars will reveal its shape, but the best approach is through a 12-inch or larger telescope. Find emission nebula NGC 604, which sits at the end of M33's northern spiral arm. Crank the magnification past 200x and look for two tiny lobes in contact.

Next is the magnitude 9.4 spiral galaxy **M74** in Pisces, which measures 10' by 9.5'. You'll find it 1.3° east-northeast of Nu (ν) Piscium. An 8-inch scope will reveal the uneven spiral arms and the mottled halo around M74's bright core. Several stars located much closer to Earth are superimposed on the galaxy.

Our next object is this list's only planetary nebula, **M76** in Perseus. It's dim

M33: PATRICK WINKLER. M76: DAN CROWSON. M45: KASRA KARIMI. M77: DAN CROWSON

(magnitude 10.1) and small (65"), but certainly worth a high-powered look. Also known as the Little Dumbbell, it can be found 1° north of Phi (ϕ) Persei. An 8-inch scope will show you the two lobes that gave the nebula its common name. If you have access to a 16-inch, you might spot some of the large, diffuse halo that surrounds M76's inner region.

Next up is open cluster **M34** in Perseus. At magnitude 5.2, it's bright enough for most amateurs to spot without optics from a dark site. Look for it 5° northwest of Algol (Beta Persei). A 4-inch scope lets you count more than 30 stars in an area 35' across. At 100x, look for chains of faint stars looping across the field of view.

Our penultimate target for this mini-marathon is spiral galaxy **M77** in Cetus. It glows at magnitude 8.9 and measures 7' by 6'. You'll find it less than 1° southeast of Delta Ceti. When you observe it, spend your time searching the disk that surrounds it for signs of mottling. Through large scopes, look for the galaxy's tightly wound spiral arms, the brightest of which lies southeast of its core.

Finally, we arrive at **M45** in Taurus, the Pleiades. At magnitude 1.6, it's the sky's brightest star cluster. Why Messier included it in his catalog of cometlike objects, we'll never know. M45 is also known as the Seven Sisters, but naked-eye observers with good vision, patience, and a steady sky often see more than seven stars in the 110'-wide cluster. How many can you count? Telescopes reveal fainter stars throughout the cluster but also spread them out, so fewer populate a given field of view. M45 seems most pleasing to the majority of amateur astronomers through 10x binoculars.

OK, it's your turn now. On the next clear and moonless night, set up your scope, get comfortable, and use this list to help you run the fall Messier mini-marathon!

Michael E. Bakich *is a contributing editor of* Astronomy.

M77

M45

Astronomy magazine 2022 Star Products

Our 12th annual STAR PRODUCTS

BY PHIL HARRINGTON

Welcome to the 12th annual Star Products awards. This year, as in the past, we scoured the market in search of the 35 best new and unique astro products. Our winners this year, presented in no particular order, offer a mix for newbie and veteran hobbyists alike.

***Phil Harrington** is a contributing editor of* Astronomy *and a dedicated equipment collector.*

1 Baader Semi APO Filter

Apochromatic refractors erase the chromatic aberration that plagues conventional achromats by either using exotic glass in the objectives or incorporating three or more objective elements, or both. But APOs can cost many times more than a comparably sized achromat. If you long for that level of performance but don't have the budget, Baader offers a cost-effective solution. Their "semi-apochromatic" filters simply screw into the barrel of any 1.25" or 2" eyepiece or star diagonal. Results are immediately obvious, even around unforgiving targets like the Moon and Venus.

75.63 euros (1.25"); 136.97 euros (2") • www.baader-planetarium.com

2 Baader SunDancer II H-alpha Filter

Baader's SunDancer II can turn any telescope into a hydrogen-alpha (Hα) solar scope. With it in place, observers will enjoy ever-changing views of prominences and other details on the solar surface. For telescopes smaller than 3.1 inches (8 centimeters) in aperture, no further accessories are required. For larger telescopes, an additional D-ERF energy protection filter is needed, unless the scope is stopped down to 3.1 inches (8 cm). Once connected to power, the SunDancer II automatically heats up to the optimum operating temperature for safe solar viewing and photography.

2,978.99 euros • www.baader-planetarium.com

3 Canon EOS R6 Mirrorless Camera Body

Conventional digital single lens reflex (DSLR) cameras use a mirror to divert light to the viewfinder. The downside is that when the mirror flips up as the shutter is triggered, vibrations from mirror slap can blur the image. Canon's EOS R6 mirrorless camera uses a small LCD display in the viewfinder to show exactly what is in view, eliminating the mirror and any vibration. The 20-megapixel sensor has an ISO range between 100 and 102,400 (expandable to 204,800). Digital noise, akin to grain in film, is low even into mid- to high-speed settings.

$2,499 • www.usa.canon.com

4 Buckeyestargazer Duncan Mask for SCT Collimation

Telescope optics must be properly collimated for best performance. To help owners of Schmidt-Cassegrains achieve this goal quickly, Buckeyestargazer offers a Duncan mask that fits in front of a scope's corrector plate. Once it is at ambient temperature, aim your telescope at a bright star high in the sky. Place the mask onto your scope and excessively defocus the image; you should see three arcs that match the mask's three cutouts. Now, slowly bring the star into focus, and its image will be split into three lines. Use your scope's three collimation screws until the lines form a perfect Y, touching in the center.

$23 to $27 (5-inch to 8-inch); $25 to $34 (9.25-inch to 11-inch); $36 to $47 (12-inch to 16-inch) • www.buckeyestargazer.net

5 Avalon Instruments T-Pod Max

Tripods have it tough. They must bear the weight of a telescope, its mount, and various accessories, all without flexing under the load. Avalon Instruments' T-Pod Max tripod is designed to do all that with style. Made of anodized aluminum, the T-Pod Max weighs only 26.5 pounds (12 kilograms), yet can support up to a stated 440 pounds (200 kg). The extendable legs raise the tripod's base from 33 to 51 inches (85 to 130 cm), while the entire tripod collapses to 39 inches (99 cm) for easy carrying. The T-Pod Max comes in red or black and is compatible with mounts from Losmandy, iOptron, Vixen, Celestron, Sky-Watcher, and others.

1,382.40 euros • www.avalon-instruments.com

6 APM EMS SD-Apo Bino 140mm F/7 Telescope

If you believe, like me, that "two eyes are better than one" and you want to take that to the nth degree, then APM's EMS SD-Apo Bino 140mm F/7 Telescope is for you. A matched pair of 5.5-inch (14 cm) apochromatic refractors are teamed to produce unparalleled true-binocular views. The APM binoscope is outfitted with matching oversized 3.7" focusers and an image-erecting prism system, all mounted on a nicely crafted wooden fork mount.

12,596.64 euros • www.apm-telescopes.net

7 Astro-Tech 10.5mm 1.25" PF Eyepiece

Astro-Tech offers its Premium Flat Field (PF) line of eyepieces in five different focal lengths ranging from 5.5mm to 25mm. All fit standard 1.25" focusers. The 10.5mm PF eyepiece is a sweet spot in the lineup; it has a 60° field of view and produces excellent magnification in most instruments for lunar and planetary viewing. Its five-lens/four-group design delivers views that are flat across the field and free of aberrations with a comfortable 16mm of eye relief.

$55 • www.astronomics.com

8 Celestron Dew Prevention Line

Celestron recently introduced an integrated system of tools to combat the age-old problem of nighttime dew accumulating on your optics. First, they offer a series of aluminum dew shields customized to fit their 6-inch to 14-inch Schmidt-Cassegrain instruments. These reduce radiative cooling of the SCT corrector plate, while also blocking stray light. Next, Celestron's dedicated Dew Heater Ring — available for 5-inch to 14-inch SCTs — permanently replaces the original factory retaining ring around the corrector, making it one less thing to forget when heading out at night. The heater rings are specifically designed to be paired with Celestron's Smart DewHeater Controller, which automatically senses environmental conditions and provides just enough heat to keep dew at bay.

$109.95 to $299.95 (6-inch to 14-inch dew shield); $39.95 to $159.95 (5-inch to 14-inch heater ring); $259.95 (Smart DewHeater Controller 2x) • www.celestron.com

9 Explore Scientific FirstLight 8" Dobsonian Telescope

To me, an 8-inch (20 cm) reflector is close to the perfect telescope. It's large enough to pull in thousands of deep-sky objects, yet small enough to set up quickly for an impromptu night out. Explore Scientific's FirstLight 8" embodies that philosophy. The Dobsonian mount is easy to assemble with a few tools and even easier to use. The scope comes with a focuser that accepts both 1.25" and 2" eyepieces, a 25mm eyepiece, a red-dot viewfinder, an accessory tray, and a smartphone adapter for photos.

$699.99 • www.explorescientificusa.com

10 CATSEYE BLACKCAT XLV-WIFI Cheshire

Anyone who is familiar with collimating a Newtonian knows that it often requires multiple trips between the collimation tool in the focuser and the adjustment screws at the back of the mirror cell. CATSEYE has come up with an ingenious solution to eliminate that back-and-forth process by coupling a small Wi-Fi camera with their BLACKCAT XL-ATM Cheshire eyepiece. The camera sends an image you can view on the included app, allowing you to tweak the primary's collimation while seeing the Cheshire's ring/center spot reflections directly on your iOS or Android smartphone's screen. Note: The app is not compatible with Android version 12.

$126 • www.catseyecollimation.com

11 Celestron Elements ThermoTorch 3 Astro Red

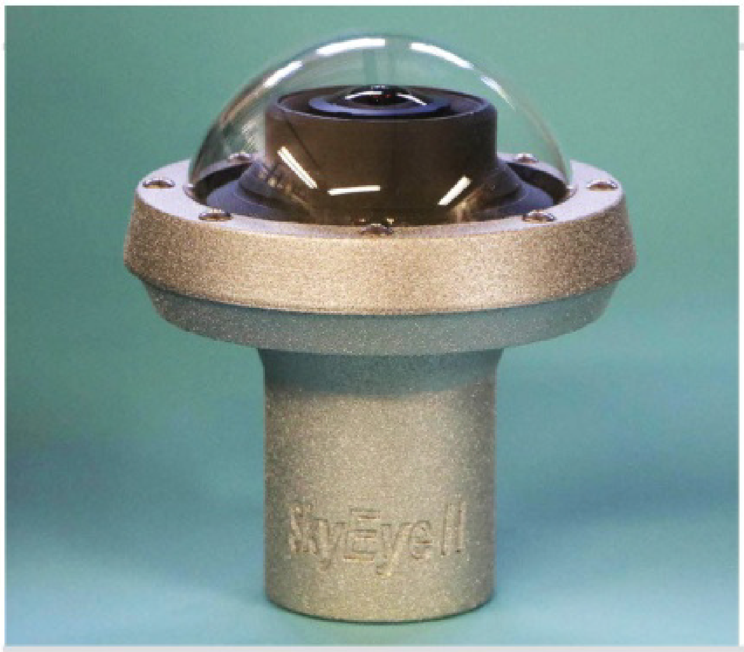
If you, like me, enjoy traveling out to dark skies as often as time permits, you will appreciate Celestron's 3-in-1 ThermoTorch 3. As the name implies, it's three essential tools in one: a red flashlight, a hand warmer, and a USB power bank. The flashlight has three brightness levels. At maximum, it's perfect for looking for a tool you've accidentally dropped, while at its lowest level, it will illuminate charts without affecting night vision. The hand warmer provides up to a stated four hours of warmth, or two hours while using the flashlight function.

$67.95 • www.celestron.com

12 Founder Optics FOT106

Founder Optics' 106mm f/6 triplet refractor is unique both inside and out. The multicoated objective consists of three fully gapped elements. Two are made of extra-low dispersion (ED) glasses (S-FPL 53 and S-FPL 51), while the third is made of lanthanum. The glossy black tube and green anodized rings, carrying handle, and 2.7" focuser really stand out. Also included are a field flattener for photography and an aluminum carrying case.

$2,499 • www.founderoptics.com



13 Interactive Astronomy SkyEye2

The SkyEye2 all-sky camera gives a full-color horizon-to-horizon view of the sky. View the ever-changing scene in real time or create time-lapse videos of satellite transits, meteor showers, aurorae, and more. Users can adjust the exposure time to between 1 second and 60 seconds, or the device can set it automatically. The camera's 6.3-megapixel color Sony STARVIS CMOS sensor is housed under a transparent dome atop a 3D-printed, weatherproofed resin body. Images can be shared to the web with the included software.

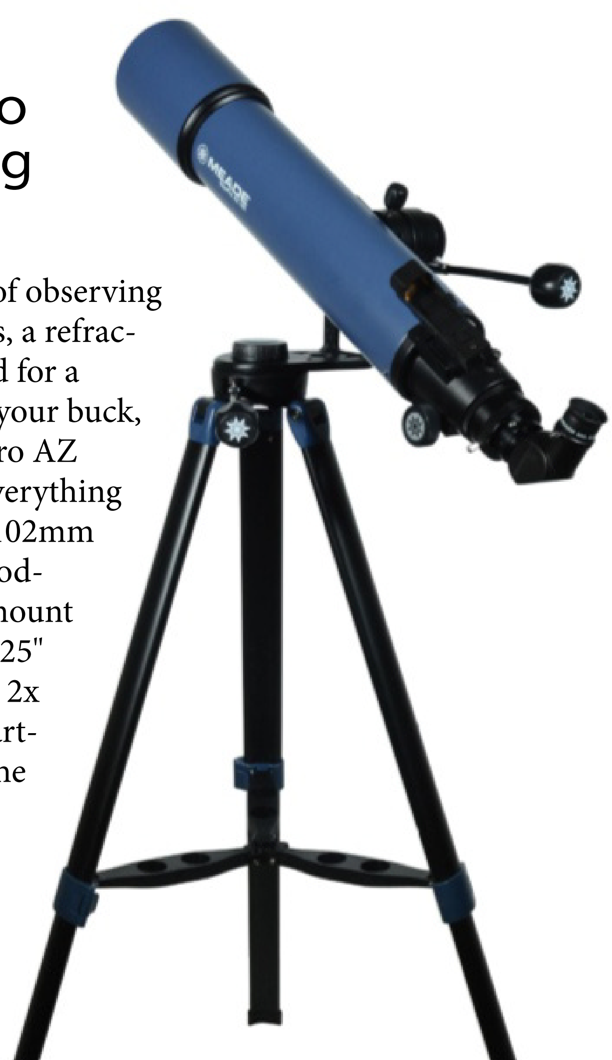
$1,399 • www.interactiveastronomy.com

14 Great American Eclipse 2024 Commemorative Coin

Many of you are probably already planning to view the 2024 total solar eclipse as the Moon's shadow races across North America. To celebrate the event, GreatAmericanEclipse.com has issued a commemorative coin for collectors. One side of the 2-inch (5 cm) coin shows the path of totality across a map of the U.S., while the other portrays the Moon over North America as the lunar shadow pinpoints the location of greatest eclipse near the town of Nazas, Mexico. Each coin comes in a clear protective case and weighs about 2 ounces (57 grams).

$12 • www.greatamericaneclipse.com

15 Meade StarPro AZ 102mm Refracting Telescope



For those who enjoy the pleasures of observing the Moon, planets, and double stars, a refractor is the best telescope design. And for a telescope that offers great bang for your buck, look no further than Meade's StarPro AZ 102mm. For under $300, you get everything you need to begin your journey: a 102mm f/6.5 achromatic refractor on a tripod-mounted, single-arm alt-azimuth mount with slow-motion controls; three 1.25" eyepieces (26mm, 9mm, 6.3mm); a 2x Barlow; a red-dot finder; and a smartphone adapter for photographing the Moon and bright planets.

$269 • www.meade.com

16 Software Bisque Paramount Apollo 600/800 Mount

Software Bisque offers some of the most advanced observatory-class telescope mounts around for serious amateurs, universities, and public facilities. Their Paramount Apollo 600 robotically driven alt-azimuth mount is designed to support telescopes weighing up to 400 pounds (180 kg), while the Apollo 800 can carry as much as 800 pounds (360 kg). Both rely on Software Bisque's industry-leading control software to ensure extremely accurate pointing and tracking. The software is available for macOS, Windows, and Linux operating systems.

$59,500 (Apollo 600); $79,500 (Apollo 800) • www.bisque.com

17 Good Directions Crescent Moon Bird Feeder

Many amateur astronomers by night are birding enthusiasts by day. The Crescent Moon Bird Feeder from Good Directions is a stylish way of melding the two interests together. With a copper finish front and back and transparent sidewalls, the Crescent Moon Feeder measures 11 inches (28 cm) long by 3.75 inches (9.5 cm) wide by 17 inches (43 cm) tall and can hold up to 4 pounds (1.8 kg) of birdseed. The bird feeder pole is sold separately.

$89 • www.gooddirections.com

18 Scopetech Mount ZERO

If you are looking for a small alt-azimuth mount that combines the ultimate in portability while supporting instruments up to 15 pounds (7 kg), then the Scopetech Mount ZERO is perfect. What looks like a simple design is actually an engineering marvel that incorporates a worm gear and wheel on each axis to eliminate the need to tighten and loosen the axis once friction is set. The mount weighs 3 pounds (1.4 kg) and measures 9.4 inches by 4 inches by 4.3 inches (24 cm by 10 cm by 11 cm) when folded flat.

$375 • **www.astrohutech.store**

19 Oberwerk BT-127XL-SD Binocular Telescope

Oberwerk recently introduced the BT-127XL-SD, the largest member of its binocular telescope family. The glossy white binoscope pairs two identical 127mm apochromatic refractors. Each has a fully coated three-element objective lens made of FCD100 and FK-61 glass to eliminate false color. Despite the size of the large objectives and prism assemblies, the BT-127XL-SD weighs only 24.5 pounds (11 kg). It comes with two 14mm eyepieces and a heavy-duty case with wheels for easy transport. A mount is sold separately.

$5,695 • **www.oberwerk.com**

20 Orion SkyScanner BL135mm Dobsonian Reflector Telescope

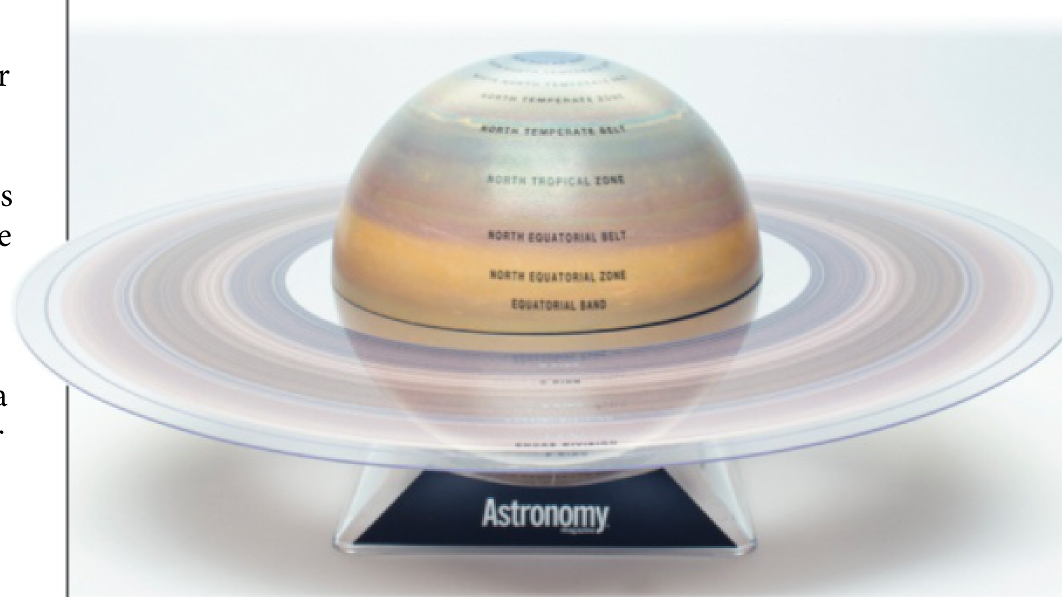
If you are looking for a low-cost starter scope, whether for a child or an adult, Orion's SkyScanner BL135mm Dobsonian is a good choice. This no-frills reflector features a 135mm f/8.1 spherical primary mirror that promises to deliver great views of the Moon, the planets, and hundreds of deep-sky objects. The steel telescope tube sits on a basic Dobsonian mount and comes with two 1.25" eyepieces, a 3x Barlow lens, a 2" rack-and-pinion focuser, and a red-dot finder scope.

$379.99 • **www.telescope.com**

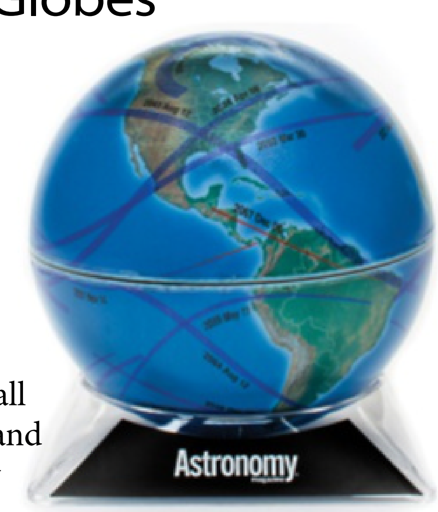
21 My Science Shop Iron Meteorite 50mm Lucite Cube

Collecting meteorites is a side hobby that many amateur astronomers enjoy. Now, you can buy a piece of the famous Campo del Cielo iron meteorite, handsomely preserved in a 2-inch (5 cm) museum-grade Lucite block for display. The Campo del Cielo meteorite slammed into Earth around 5,000 years ago, in a remote area of Argentina 620 miles (1,000 kilometers) northwest of Buenos Aires. Encased in optical-clarity resin that will not yellow or degrade with time, this 1-ounce (28 g) fragment displays the rugged shape that makes iron meteorites famous.

$150 • **www.myscienceshop.com**



22 My Science Shop 6" Saturn and Eclipse Globes



Two new globes have been added to My Science Shop recently: The Saturn Globe consists of a 6-inch (15.2 cm) injection-molded globe that identifies 17 planetary features. The detachable acrylic rings are labeled with seven regions. The 6-inch (15.2 cm) Eclipse Globe shows the paths of all total solar eclipses between 2021 and 2070. Both include acrylic display bases and informational guides.

$34.95 (eclipse globe); $49.95 (Saturn globe) • **www.myscienceshop.com**

23 Taurus T300 Dobsonian Telescope

From Myślenice, Poland, comes this line of state-of-the-art Dobsonians. Ranging in aperture from 12 to 24 inches, Taurus Telescopes are designed to deliver the ultimate in performance and portability. The 12-inch f/5 T300 measures 59.5 inches (151 cm) high when set up, yet folds into a nested pack that easily fits into the trunk of a car. It weighs 35 pounds (15.9 kg), so it can be set up quickly by one person. The instrument is sold with a made-in-house primary, a selection of focusers, truss poles, a light-blocking shroud, and mirror covers.

starting at 1,495 euros • www.taurustelescopes.com

24 QHY QHY411 CMOS Camera

If you are looking for the ultimate camera and money is no object, the QHY411 is it. QHY boasts that their QHY411 is the largest-resolution cooled CMOS camera in the world. Available in both monochrome and color versions, the QHY411 camera is built around Sony's 150-megapixel IMX411 BSI CMOS sensor. The back-illuminated IMX411 BSI measures 4.2 inches (10.6 cm) and has a resolution of 14304x10748 with 3.76-micron pixels for incredible images. The Sony chip makes the QHY411 the first scientific CMOS camera with native 16-bit A/D on-chip, with 65,536 levels.

$50,000 • www.qhyccd.com

25 Schalck Observatory Plaques

Amateur astronomer Bob Schalck offers customized plaques that are perfect for adorning any backyard or club observatory. Each plaque is custom made from rough-cut Oregon cedar to match the owner's specific telescope, with the engraved side slightly smoothed. The wood will slowly turn a light gray color as it ages, but will remain resistant to weathering, insects, and mold. Plaques measure approximately 8 inches (20.3 cm) long by 5.25 inches (13.3 cm) wide.

$25 • oceaniclaserworks@gmail.com

26 Player One Apollo-M Solar Cameras

With solar activity on the uptick, more people are becoming daytime astronomers. To help safely capture the exciting views through Hα solar scopes, Player One offers the Apollo-M Solar Camera series. All feature Sony monochrome CMOS sensors. The Max uses the 1.1-inch (2.8 cm) IMX432 sensor, while the lower cost Apollo-Solar contains the 0.83-inch (2.1 cm) IMX174 sensor and the Mini features the 0.67-inch (1.7 cm) IMX429. All are USB 3.0 compatible. Each includes DPS (Dead Pixel Suppression) technology to prevent hot and cold pixels from spoiling the image. They also use a DDR3 cache to stabilize and secure data transmission.

$499 (Apollo-M Mini); $599 (Apollo-M); $699 (Apollo-M Max) • www.player-one-astronomy.com

27 Player One Astronomy Mars Cameras

For those who prefer photographing planets, Player One offers the Mars-M monochrome and the Mars-C and Mars-C II color cameras. The Mars-M uses Sony's IMX290 CMOS sensor, while the Mars-C has the IMX462 color chip and the Mars-C II the new IMX662. The original M and C cameras feature a 1944x1096 array of 2.9-micron pixels, while the Mars-C II has a 1936x1100 array of 2.9-micron pixels. All can also function as autoguiders via a standard ST-4 port and can transform into all-day cameras with an optional all-sky kit.

$249 (Mars-C); $299 (Mars-M); $299 (Mars-C II) • www.player-one-astronomy.com

28 Photon Express Bahtinov Masks

One of the most common problems astrophotographers face is achieving a sharp focus. To solve that problem, many use Bahtinov focusing masks that fit in front of their telescope or camera lens. Once aimed at a star, the mask's three separate grids produce three angled diffraction spikes on the star. You then adjust your focus until the middle spike is centered between the other two. Photon Express offers 3D-printed Bahtinov masks made of a durable thermoplastic polyester known as PETG. Masks are available in a wide variety of sizes to fit over camera lenses and can be custom made up to 8 inches (20 cm), with plans to expand to larger scopes in the near future.

$15 (up to 60mm); $18.50 (65mm to 81mm); $21.50 (85mm to 105mm); $26.50 (106mm to 152mm) • www.jwbozeman.com

29 TS-Optics 2" LED Collimator

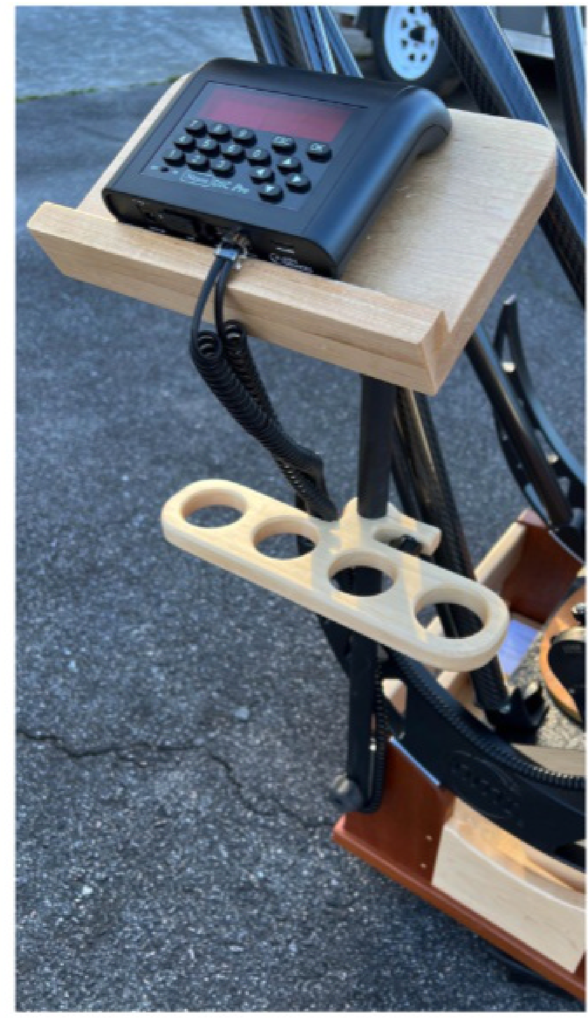
Let's get one thing straight: Unless a telescope's optics are properly collimated, image quality will suffer. The 2-inch (5 cm) LED Collimator from TS-Optics is designed specifically for Ritchey-Chrétien reflectors, but can also be used for other optical designs. To use it, aim your telescope horizontally toward a uniformly painted wall, insert the battery-powered collimator into the telescope's 2" focuser, and follow the included instructions for spot-on collimation. An instructional video is also available on the company's website.

142.02 euros • www.teleskop-express.de

30 Revolution Imager SkyRaider 80mm ED APO Refractor Long Perng

This 80mm f/6.25 refractor from Revolution Imager promises great visual and photographic results, thanks to its fully multicoated FPL53 extra-low dispersion (ED) doublet objective. The SkyRaider weighs just 6 pounds (2.7 kg) and includes a 2" rotatable, dual-speed Crayford focuser and a 2"-to-1.25" eyepiece adapter. The telescope does not include any diagonal or eyepieces.

$849.95 • www.revolutionimager.com



31 New Moon Telescopes Detachable Tablet Stalk and Eyepiece Tray

New Moon Telescopes offers a customizable tablet shelf and eyepiece tray (available separately) that can be attached to most Dobsonian mounts. As with their telescopes, New Moon's tray and shelf are finely crafted from several hardwoods, including mahogany, maple, cherry, and walnut. The tablet tray is also available in plexiglass. Each attaches to the mount's rocker box with a supplied 26-inch (66 cm) anodized aluminum tube. The platform's angle can be adjusted once installed. The eyepiece tray is available with either four 2-inch holes, or three 2-inch and two 1.25-inch holes. Each is sold separately.

$78 (plexiglass tablet stalk); $148 (hardwood tablet stalk); $98 (hardwood eyepiece tray) • www.newmoontelescopes.com

32 Sky-Watcher Flextube 400P SynScan GoTo Collapsible Dobsonian

Of the five models in Sky-Watcher's Flextube SynScan GoTo Collapsible Dobsonian lineup, the 406mm f/4.4 is the largest. Rather than using a traditional truss open-tube design, Sky-Watcher went with three tubes that slide straight up and down. This allows the optical tube assembly to collapse when stowed without major disassembly. The Dobsonian mount includes go-to control and tracking, but also lets you move the scope manually while still retaining alignment with the sky. Also included are a 2" dual-speed Crayford focuser with 1.25" adapter, a 9x50 straight-through finder scope, and two 1.25" Plössl eyepieces.

$4,680 • www.skywatcherusa.com

33 Stellarvue SVX140T Refractor

Stellarvue is famous among amateurs for its outstanding apochromatic refractors. The 140mm f/6.7 SVX140T is the newest member of Stellarvue's SVX line. The heart of the SVX140T — its fully multicoated triplet objective — uses an Ohara S-FPL-53 extra-low dispersion (ED) center element and a Lanthanum rear element for superior color correction. It is housed inside a fully baffled aluminum tube painted "instrument white." The retractable dew shield extends 12 inches (30.5 cm) in front of the instrument. The SVX140T weighs 22 pounds (9.9 kg) without the rings attached and measures 31 inches (79 cm) with the dew shield retracted. Buyers may choose from two different 3.5" focusers and a selection of flatteners with adapters. Also included are a pair of mounting rings, dust caps, and a heavy-duty carrying case.

starting at $7,395 • www.stellarvue.com

34 TPO 8" Carbon Fiber f/8 Ritchey-Chretien Reflecting OTA Telescope

Ritchey-Chretien (RC) reflectors have been favorites among professional observatories for decades, thanks to their freedom from the coma, chromatic aberration, and spherical aberration that plague other optical designs. Today, many amateurs share that same opinion of the RC design. The TPO 8-inch f/8 RC telescope from Oceanside Photo and Telescope (OPT) takes this design and packages it in a strong carbon-fiber tube that weighs only 16.4 pounds (7.4 kg). Both the concave hyperbolic primary and convex hyperbolic secondary mirrors are made from low-expansion quartz and layered with 99-percent dielectric coatings. The scope also includes a 2" dual-speed Crayford focuser, as well as both Vixen and Losmandy dovetail plates to secure it to today's most popular mounts.

$1,449 • www.optcorp.com

35 Sightron Nano Tracker

Many photographers enjoy taking breathtaking panoramic time-lapse images of the night sky. While some use elaborate equipment for those results, Sightron offers a solution that is both small and affordable. The Sightron Nano Tracker measures just 2.4 inches by 3.9 inches by 1.7 inches (6 cm by 9.8 cm by 4.4 cm) and weighs less than a pound (400 g). The Nano Tracker can hold cameras and lenses weighing more than 4 pounds (1.8 kg) while following the sky either at full- or half-sidereal rate. The latter is great for dramatic time-lapse shots of rising and setting stars. The device is powered by either three AA batteries or an external USB source, sold separately.

$315 • available in the U.S. at **www.starfieldoptics.com**

Time-tested double stars

None of the 35 targets on this list will disappoint.

Three of my favorite double stars visible in the October sky appear on Phil Kane's compiled list: Gamma (γ) Andromedae (left), Gamma Arietis (middle), and Gamma Delphini (right).
ALL IMAGES: ALAN DYER

BY GLENN CHAPLE
Glenn has been an avid observer since a friend showed him Saturn through a small backyard scope in 1963.

Long-time readers of this column know that I have a passion for double stars. I've featured them numerous times here in Observing Basics, and before that in a column devoted to double stars in *Deep Sky Monthly* and *Deep Sky Magazine*.

So it's no surprise that I'm often asked for my all-time favorite double stars. In truth, my list tends to be heavily influenced by what's accessible from the mid-northerly latitude where I live. Not only that, but my list is in constant flux; a current roster of my 100 favorites would be slightly different from lists compiled in past years.

Longtime amateur astronomer Phil Kane of Burney, California, however, has a more systematic way of selecting the best double stars visible from mid-northern latitudes. Here's how he does it.

"I recently had an occasion to look over the Astronomical League's 2018 list of its 100 best double stars," says Kane. "Alongside it in my 'Doubles' folder is my oldest 'Best Doubles' list from 77 years earlier: Bernhard, Bennett, and Rice's *New Handbook of the Heavens* [Whittlesey House, 1941], which featured 96 pairs. It turned out that these two [lists] shared 54 doubles. This means, together, they did not agree on 46 + 42 = 88 other pairs. Because no one would expect any two observers to select exactly the same 100 doubles, I was not particularly surprised."

However, the differences between the two lists encouraged Kane to compare them to three more: Brian Skiff's list from *Men, Monsters and the Modern Universe* (Willman-Bell, 1989; 140 pairs), James Mullaney's from *Sky & Telescope* (July 2004, Jan. 2005, Sept. 2006, and May 2007; 100 pairs), and my own list in *Astronomy*'s March 2016 issue (110 pairs).

In these lists, Kane says "there are 320 unique doubles" — pairs that appear only on one of the lists. On the other hand, "my comparison of all five lists found only 35 doubles to be on all of them.

"These 35 are also in my oldest handbook with a limited selection: *In Starland With a Three-inch Telescope* [Putnam, 1909] by William T. Olcott. And they are part of the granddaddy of all lists, Admiral W.H. Smyth's *The Bedford Catalogue* [Sotheby, Wilkinson & Hodge, 1844]," says Kane, adding that "these 'survivors' — consistently recognized for over 175 years by skilled observers — should certainly be considered for the favorite 35 double stars of all."

Kane's final list of 35 targets includes a trio of my all-time favorite pairs currently observable in the October evening sky: Gamma (γ) Delphini, Gamma Arietis, and Gamma Andromedae. The trio are all doubles that are bright and wide enough to be enjoyed with even the smallest backyard scope. They are especially delightful when viewed with a modest 2.4-inch refractor and a magnification of 60x to 75x.

Gamma Delphini is the star that marks the Dolphin's snout. It consists of magnitude 4.4 and 5.0 component stars separated by 8.9"; I perceive their colors as yellowish and bluish. While in the area, also look 15' southwest of Gamma Delphini for the delicate little pair Struve 2725 (Σ2725; magnitudes 7.5 and 8.2, separation 6.2").

Gamma Arietis, meanwhile, is a striking near-twin system, composed of sparkling white magnitude 4.5 and 4.6 stars separated by 7.4". To me, pairs like this take on the appearance of the headlights of some distant cosmic automobile.

The trio are all doubles that are bright and wide enough to be enjoyed with even the smallest backyard scope.

Kane's list also includes the colorful yellow and blue Albireo (Beta [β] Cygni), regarded by many amateur astronomers as the finest double star of all. I consider it rivaled by the topaz and sapphire gemset Gamma Andromedae, primarily because the latter's magnitude 2.3 and 5.0 component stars are 9.8" apart (less than one-third the separation of Albireo's stars), as well as much more eye-pleasing at medium and high magnifications.

If you'd like a copy of Phil Kane's "35 Time-Tested Double Stars," or if you have any questions, comments, or suggestions relating to this column, email me at gchaple@hotmail.com. Next month: observing variable stars. Clear skies!

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Steve's uncertainty principle

At the limits of human vision, certainty isn't easy to come by.

The literature is full of specialized uncertainty principles, like this example from a 2003 Dilbert comic strip.

Heard of Heisenberg's uncertainty principle? It says the more certain we are of a quantum particle's position, the less certain we are of its velocity, and vice versa. While that deals solely with the quantum world, "Steve's uncertainty principle" deals with the threshold of visual observations in the macroscopic world. Unlike the Heisenberg uncertainty principle, however, Steve's is something I just made up.

The impetus to create Steve's uncertainty principle came from two sources. The first was an observer who was curious why I don't use percentages to describe how certain I am in published observations — as in, "I'm 75 percent sure I saw something." The second was an observer who was more than 50 percent confident of sighting a dim object after receiving one decent photon hit, but was nervous to report it. (Experiments show that the human vision system can detect a single photon, though the brain tends to filter out a single hit if not primed by earlier photons.) As both cases concern degrees of visual uncertainty, let me share some personal thoughts, which have helped me sleep well at night.

If I'm uncertain of an observation, I generally do not report it.

A principled approach

Steve's uncertainty principle states that any visual threshold observation (that is, on the single photon level) remains uncertain until a 100 percent confidence level is achieved. In this principle, then, three levels of confidence exist: 1) I see it (100 percent); 2) I don't see it (0 percent); 3) I'm uncertain, but will likely try again later until I either succeed or fail. If I'm uncertain of an observation, I generally do not report it — unless I want to encourage others to join in the challenge, which can enhance the fun.

Intermediate percentages are not part of this principle because the result is always the same: uncertainty. The way I see it, visual threshold observations either provide enough photon hits to make an observation certain, or they don't. How many hits are required to bring about 100 percent certainty? As many as it takes.

An uncertain observation

Here's an example of an uncertain observation I've never published (well, until now). Some years back, an astronomer calculated that if I were to search for the sliver of a hyper-young Moon from the nearly 14,000-foot (4,200 meter) summit of Mauna Kea in Hawaii on a given date, I should be able to see it near the limit of perception. It was an extreme observation — the closeness of the waxing Moon to both the setting Sun and the horizon made it a race against time. Nevertheless, I was up for the challenge.

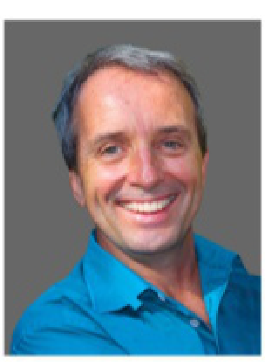
When the golden moment occurred, try as I might, I could not convince myself that I saw it. Several times I thought I saw a thin sliver of light around the Moon's predicted position, but the sightings were not enough to make me feel confident. I also noticed dim irregularities in the air, which appeared as hyperfine whiskers of light. Were my fleeting glimpses only enhancements of these minute atmospheric striations? Maybe, maybe not. I couldn't be sure.

Furthermore, whenever I did catch a momentary suspect, I wasn't sure if it took the form of an arc. Then again, the superthin horns of the young Moon might have been too difficult for me to see due to limited contrast. So perhaps I was seeing only the flattest, brightest, portion of the crescent.

Is it possible that I really did see this hyper-thin Moon? Yes, but it's also possible I didn't. In the end, I told the astronomer, "No, I didn't see it." I provided no percentage of certainty. But it was a learning experience, and I may try to repeat the observation in the future. Uncertain observations on particular nights do not negate the chances of certain observations on other nights.

I encourage you to apply my principle to your own observations. Repeated attempts at observing a difficult object may just be the key to helping you decide whether or not you can see it — so you can go to sleep feeling confident about your decision.

As always, send your certain, or uncertain, observations to me at sjomeara31@gmail.com.

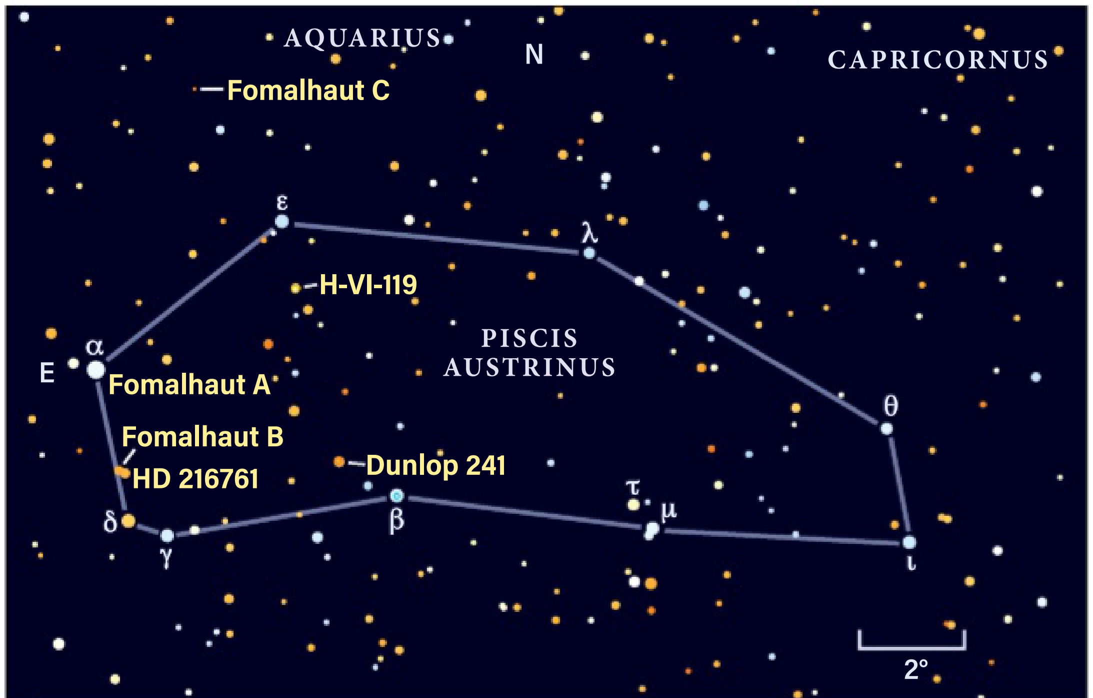


BY STEPHEN JAMES O'MEARA
Stephen is a globe-trotting observer who is always looking for the next great celestial event.

BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/OMeara**

Something fishy

Take a page out of Captain Ahab's book this autumn.



Though not home to the brightest stars, the autumn sky contains a few worthy catches.
ASTRONOMY: ROEN KELLY

BY PHIL HARRINGTON
Phil received the Walter Scott Houston Award at Stellafane 2018 for his lifelong work promoting and teaching astronomy.

The autumn sky is not known for bright stars. True, we are still enjoying the brilliant leftovers from the summer early in the evening and the dazzling winter stars toward midnight. But the autumn sky itself is home to only one truly bright star.

Crawling along our southern horizons this month is the season's brightest sun, **Fomalhaut (Alpha [α] Piscis Austrini)**, the "mouth of the whale." Fomalhaut is only about 25 light-years away and is the 18th brightest star in the sky. It outshines old favorites like Deneb (Alpha Cygni) and Castor (Alpha Geminorum), yet few people give it more than a passing glance, if any at all. That's probably due to its low location in most northern skies.

The autumn sky is home to only one truly bright star.

That isolated position, however, makes finding Fomalhaut a snap. Just head out any October evening and look close to the southern horizon. It's the brightest star — maybe the only star — you'll see in that direction. At midmonth, it crests above the horizon, or culminates, at 10 P.M. local daylight time.

Fomalhaut is a brilliant white spectral type A star. But when you raise your binoculars its way, it may look more like a colorful strobe. That vibrant display is caused by turbulence in Earth's atmosphere, which is further amplified by the star's low altitude.

Fomalhaut is actually a triple-star system. The brighter companion star, 6th-magnitude Fomalhaut B, is nearly a light-year away from Fomalhaut A, placing it almost 2° to its south in our sky. Fomalhaut B is an orange dwarf sun also known as the variable star **TW Piscis Austrini**. Over a 10.3-day period, it varies in brightness slightly from magnitude 6.44 to 6.51. While that is too subtle to detect through binoculars, you should notice the star's golden tint. In fact, you'll probably see two colorful stars there. The second, **HD 216761**, lies just 8' southeast of TW and is half a magnitude brighter. Although they are nowhere near each other in space, they do form a lovely optical double through binoculars.

And for the record, the system's third member, Fomalhaut C, is a 13th-magnitude red dwarf more than 5° to Fomalhaut A's northwest.

Fomalhaut draws our attention to the dim constellation Piscis Austrinus the Southern Fish. You'll find its outline, which reminds me more of a pickle than a fish, along the southern edge of this month's Star Dome (see page 34). None of the Fish's other stars crack 4th magnitude, so beginning at Fomalhaut, use your binoculars to trace out the constellation.

If you're game for a challenge, pause when you come to **Beta (β) Piscis Austrini** and take a close look. Beta is a binary star, pairing a magnitude 4.3 primary star with a magnitude 7.8 companion just 30.3" south. That's barely resolvable with 10x binoculars under ideal conditions. But with it so low in the sky, more magnification may be required to ferret it out.

If splitting Beta is a bit much, there is an easier double star hiding in plain sight 1.3° to the northeast. **Dunlop 241** was discovered by 19th-century Scottish astronomer James Dunlop and included in his 1829 compilation *Approximate Places of Double Stars in the Southern Hemisphere*. Often abbreviated Δ241 on charts, Dunlop 241 is made up of two golden K-type suns. The system's brighter primary star shines at magnitude 5.8, while its fainter cohort is magnitude 7.8. You'll enrich their subtle colors by slightly defocusing the view.

Let's hunt down one final double star in the Southern Fish. Scan across the Fish's form to Epsilon (ε) Piscis Austrini, 6° northeast of Beta. As you do, keep an eye out for **H-VI-119**, another pretty and underappreciated pair. First published in volume 6 of William Herschel's double star catalogs of 1782 and 1784, H-VI-119 consists of magnitude 6.4 and 7.5 stars. Take a close look and you'll see that the primary is a rich yellow color, while the secondary is a delicate blue.

Do you have any questions, comments, or suggestions for future targets? Please contact me through my website, philharrington.net. Until next month, remember that two eyes are better than one.

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A kids' tour of space
Black Dog & Leventhal
New York, New York

In their new book *A Child's Introduction to Space Exploration*, *Astronomy* Editor David J. Eicher and Contributing Editor Michael E. Bakich guide young astronomers through the universe. Readers get a history of global space exploration, meet the scientists they should know, learn about STEM experiments to perform at home, and more!

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Collect JWST
U.S. Postal Service
Washington, D.C.

In celebration of the successful launch of the James Webb Space Telescope (JWST), the U.S. Postal Service is issuing postage commemorating the iconic telescope. The 20-stamp set, released on Sept. 8, features a rendering of JWST in space. Its hexagonal mirror reflects the cosmos it has now begun to observe.

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iOptron
Woburn, Massachusetts

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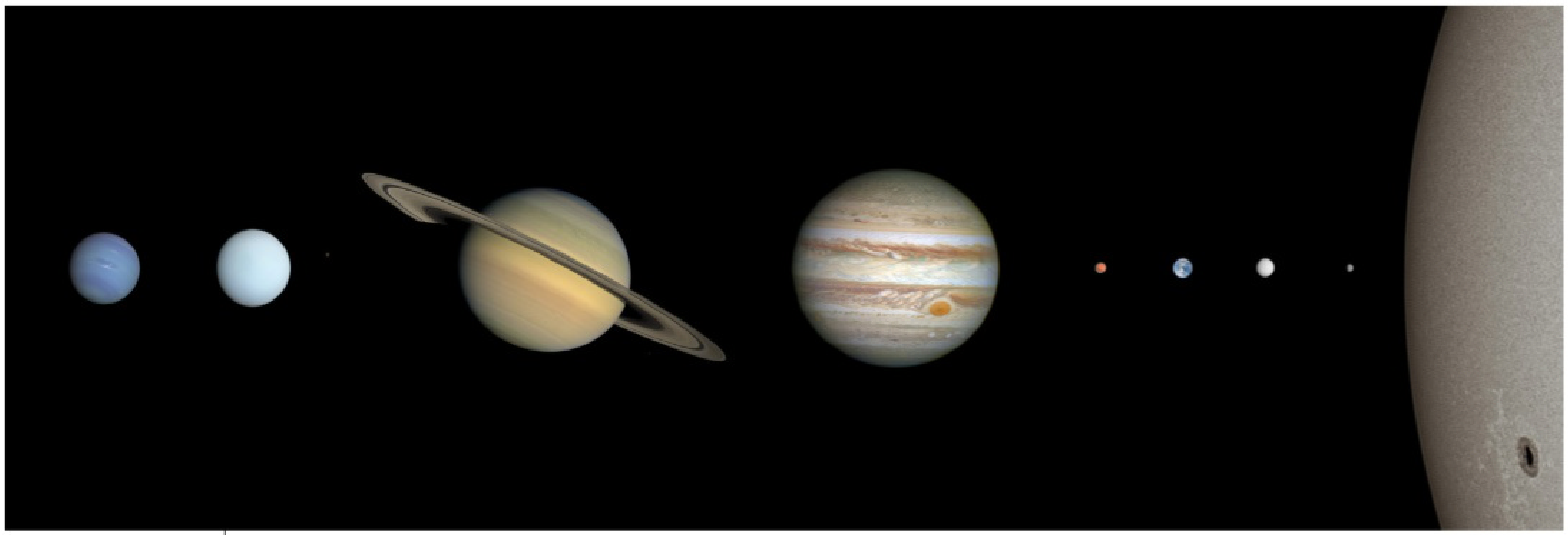


Scientists are still trying to understand why the giant planets in our solar system rotate higher speeds compared with the terrestrial planets. MOTLOASTRO/WIKIMEDIA COMMONS (SUN); NASA (MERCURY, VENUS, EARTH, JUPITER [WITH ESA], SATURN, URANUS, NEPTUNE); ESA (MARS)

Speedy giants

Q | WHY DO THE GIANT PLANETS ROTATE SO MUCH FASTER THAN THE TERRESTRIAL PLANETS IN OUR SOLAR SYSTEM?

Jim Repass
Clinton, Washington

A | We still don't fully understand what determines the rotation rate of giant planets; this is a key open topic in planetary science.

Let's take a look at the differences between the giant planets — Jupiter, Saturn, Uranus, and Neptune — and the terrestrial planets — Mercury, Venus, Earth, and Mars. The most obvious difference is that whereas the terrestrial planets are solid bodies, the giant planets are *mostly* gas (Jupiter and Saturn) or ice (Uranus and Neptune). The fact that they don't have a solid, visible surface makes it challenging to measure their spin. But it's not impossible: The interior rotation periods of the giant planets are about 10 hours for Jupiter and Saturn, 17 hours for Uranus, and 16 hours for Neptune.

However, it is unclear whether giant planets have uniform rotation. The visible portion of their atmospheres have zonal winds — alternating jets flowing east to west or vice versa. These jets can be prograde, meaning they travel in the same direction as the planet's rotation, or retrograde, moving against the rotation.

For a long time, it was unknown how deep the winds penetrate and how they relate to the rotation of the deep interior. Recently, thanks to data from space missions like Juno and Cassini, scientists determined that the winds of Jupiter and Saturn reach depths of some 1,800 miles (3,000 kilometers) and 5,600 miles (9,000 km), respectively. But this is barely scratching the surface of these planets, which have radii on the order of tens of thousands of miles.

For Uranus and Neptune, models suggest that winds don't penetrate deeper than around 620 miles (1,000 km). But the ice giants have been visited only once — by Voyager 2 — over 30 years ago, so our data are limited.

Despite all these questions, we do have some idea of what makes the outer planets such fast rotators. We believe that it's linked to their formation history and their relatively high masses.

The earliest stage of giant planet formation is thought to be the formation of a solid core made of heavy elements (rocks and ices). If the core is massive enough (a few times the mass of Earth), it can accrete hydrogen and helium gas from the disk. As gas is accreted onto the planet, it increases the total angular momentum of the world, which, in turn, leads to rapid rotation. The exact details of these processes and how the rotation of the planet evolves with time are yet to be determined, however.

Ravit Helled
Planetary Scientist, Center for Theoretical Astrophysics & Cosmology, Institute for Computational Science, University of Zurich, Zurich, Switzerland

Q | HOW FAR FROM EARTH WOULD A TELESCOPE HAVE TO BE TO CAPTURE A DIRECT VIEW OF THE BLACK HOLE AT THE CENTER OF THE MILKY WAY, UNIMPEDED BY DUST CLOUDS?

Dan Nicolaescu
Clifton Park, New York

A | At the center of our galaxy sits a supermassive black hole known as Sagittarius A*, or Sgr A* for

short. This black hole was first discovered in 1974 as a pointlike radio source. Sgr A* cannot be viewed with an optical telescope because, as you point out, interstellar dust and gas clouds in the plane of the Milky Way obscure any radiation coming from the center of the galaxy.

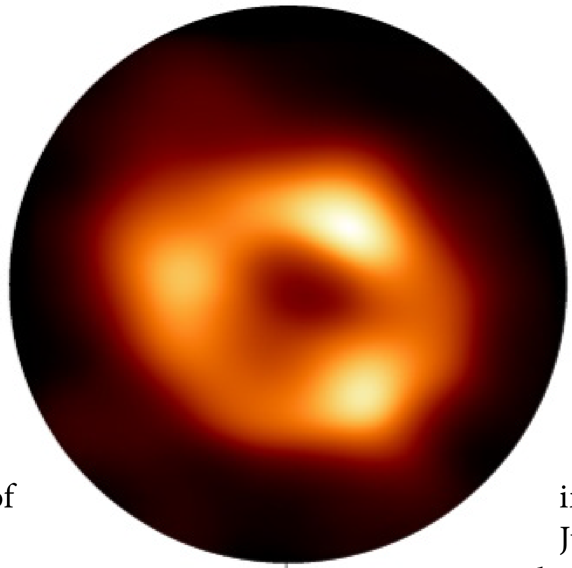
And at around 26,000 light-years away, there is currently no realistic way for us to get an optical telescope close enough to Sgr A* that the dust and gas would not be a problem. Remember, the farthest human-made objects are the Voyager spacecrafts, which launched in 1977 — neither of which have definitively passed outside the solar system at the time of writing.

If we were in contact with an advanced alien civilization near the center of the galaxy, theoretically they could send us an image. But, in the meantime, researchers have come up with an even better solution: the Event Horizon Telescope (EHT). You've probably already seen the news by now: The EHT revealed the first image of Sgr A* earlier this year, on May 12. This was just the second time the world has ever seen a black hole — the first was M87*, three years prior.

The EHT is a global array of 11 telescopes. Instead of optical light, these telescopes can see in radio wavelengths, meaning they can peer past the dust and gas and see the black hole. Or, more accurately, they can see the very bright material swirling into the black hole, known as the accretion disk. The shadow of the black hole's event horizon — the point of no return, where not even light can escape the object's gravity — appears silhouetted against the accretion disk.

Because of its proximity and mass (approximately 4 million times that of the Sun), Sgr A* presents an unparalleled opportunity to study how physics behaves under such extreme gravity. It also offers a fantastic opportunity to study how material is captured, accreted, and ejected by a black hole.

Farhad Yusef-Zadeh
Professor, Department of Physics and Astronomy, Northwestern University, Evanston, Illinois



LEFT: The Event Horizon Telescope released the first image of the Milky Way's supermassive black hole, Sgr A*, on May 12. EHT COLLABORATION

Q | IF THE ACCELERATING EXPANSION OF THE UNIVERSE IS DRIVING GALAXIES AWAY FROM EACH OTHER, HOW IS IT THAT THE ANDROMEDA AND MILKY WAY GALAXIES ARE ON A COLLISION COURSE?

Steve Amundson
Littleton, Colorado

A | As you point out, the universe is expanding, carrying the galaxies inside it away from each other like raisins inside rising bread dough. This means that one day, far in the future, inhabitants of our galaxy will not see any other galaxies in the night sky.

That doesn't mean that galaxies that are near to one another don't interact, however.

Just as Earth's gravity might pull on a nearby asteroid, sending it on a collision course with our planet, the Andromeda and Milky Way galaxies interact with each other gravitationally. This has resulted in the two galaxies falling toward each other at a rate of about 37 miles per second (60 km per second). Because Andromeda is 2.5 million light-years away — with 1 light-year equivalent to 5.9 trillion miles (9.5 trillion km) — this galactic crash won't occur for 4.5 billion years. And thankfully, the space between stars is so great that it's unlikely anything will truly collide. But the merger will change the paths of stars within each galaxy.

As it turns out, a majority of the Milky Way halo was "formed by the merging of numerous progenitor galaxies," according to a paper published in *The Astrophysical Journal* earlier this year. Though the exact number of times our galaxy has merged with another is unclear, what is clear is that the Andromeda collision won't be the first time the Milky Way has merged with another galaxy. Nor will it be the last.

Our galaxy is part of a galaxy cluster known as the Local Group. One day, this collection of nearly 100 galaxies may have all merged. And there's even evidence that the Local Group might itself merge with the closest large galaxy cluster, the Virgo Cluster!

Caitlyn Buongiorno
Associate Editor

BELOW: This view imagines the Andromeda-Milky Way collision as seen from Earth 3.75 billion years from now. NASA; ESA; Z. LEVAY AND R. VAN DER MAREL, STSCI; T. HALLAS; AND A. MELLINGER

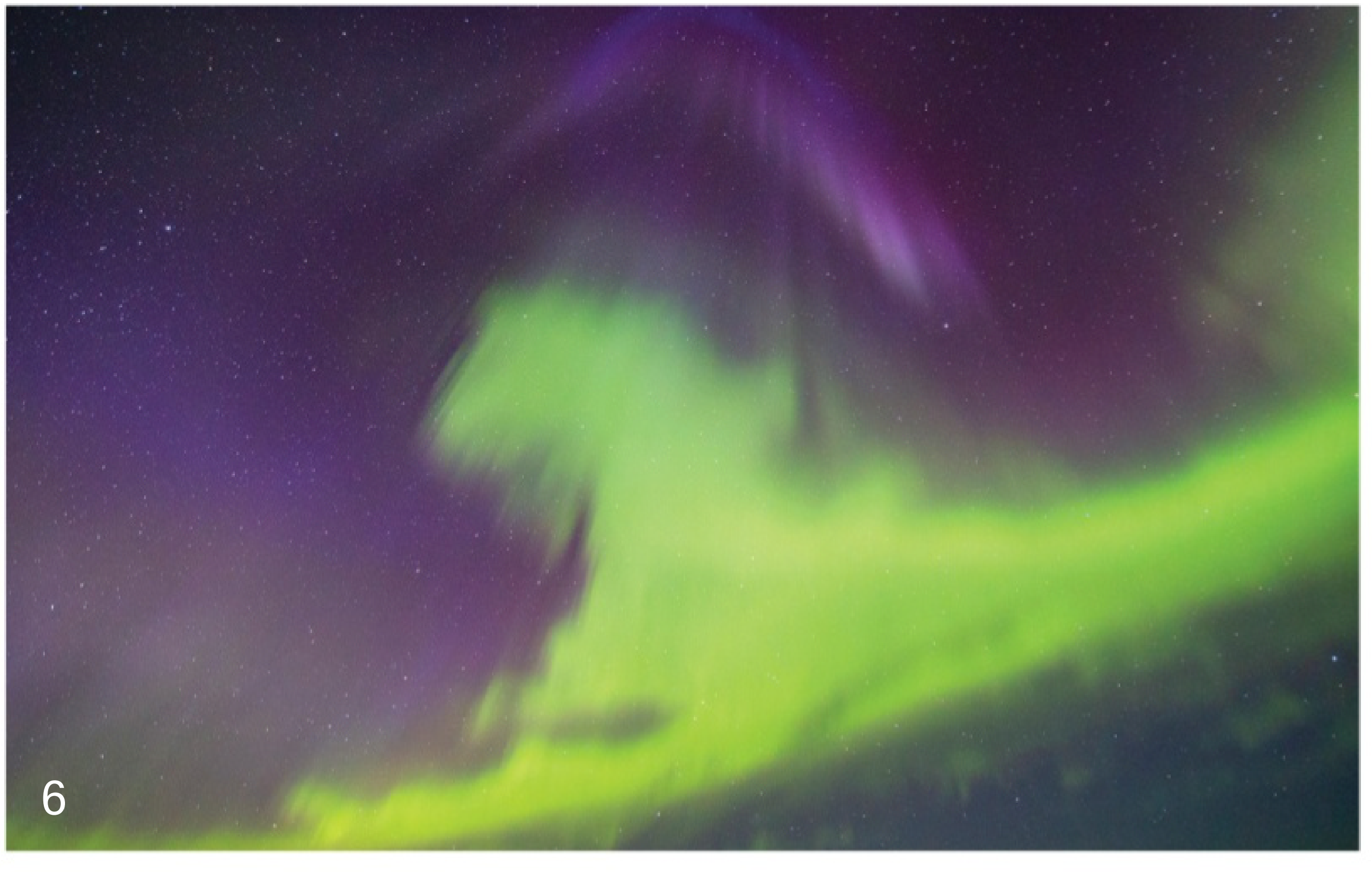
SEND US YOUR QUESTIONS

Send your astronomy questions via email to askastro@astronomy.com, or write to Ask Astro, P.O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

Cosmic portraits

1. ANDROMEDA'S GHOSTLY SHELL
The familiar Andromeda Galaxy (M31) shows off its delicate, wispy fringes in this deep three-panel mosaic. Faint protrusions from the edges of the stellar halo are evidence of previous gravitational encounters with other galaxies. The imager took 26 hours of exposure from a Bortle 1 site with a Nikon D90 at ISO 800 and a 300mm f/4 lens.
• William Ostling

2. COSMIC CRUSTACEAN
The Prawn Nebula (IC 4628) is a stellar nursery roughly 6,000 light-years away in Scorpius, teeming with young stars whose intense radiation is setting the surrounding gas aglow. The image represents eight hours of exposure with a 12-inch scope and was processed in the Hubble palette. ***• Kfir Simon***



3. PLANETS ON PARADE
In June, all seven major planets were visible in the morning sky, and this imager caught all of them rising above the Forbidden City in Beijing. The photographer captured 8-second exposures with a 20mm lens at ISO 200. **• *Zheng Zhi***

4. SOLAR SNAKE
A large solar filament winds its way across the surface of the Sun in this Hα image from June 19. The shot was taken through a 2.4-inch solar telescope with a 3x Barlow lens. **• *Behyar Bakhshandeh***

5. K2'S PEAK
Comet C/2017 K2 sports a dust tail over 1° long — plus a faint ion tail appearing to stretch toward the globular cluster M10 — in this July 15 image. One day earlier, the comet made its closest approach to the Sun. This image was made with 33 minutes of LRGB data taken with a 12-inch scope. **• *Gerald Rhemann***

6. KAIJU CLASH
A monstrous patch of green aurora roams this Alaskan skyscape as a purple coronal aurora forms directly overhead. The imager says the pair reminded him of "Godzilla with Mothra on the attack!" This 8-second shot was taken with a 16mm f/2.8 lens at ISO 3200. **• *John Chumack***

SEND YOUR IMAGES TO:
Astronomy Reader Gallery, P.O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to **readergallery@astronomy.com.**

WEBB SETS SAIL INTO THE COSMOS

It took scientists and engineers six months to get the James Webb Space Telescope (JWST) ready for its debut, but the wait was worth it. One of the observatory's first targets was the Southern Ring Nebula (NGC 3132) in Vela the Sails. JWST's Near-Infrared Camera captured this planetary nebula, created over the past several thousand years as a dying Sun-like star ejected at least eight shells of gas and dust. This stellar ember appears as a faint dot along the lower-left diffraction spike radiating from the bright star at the image's center. Turbulence created as these two stars rapidly orbit each other sculpts the nebula's intricate rings. NASA/ESA/CSA/STSCI/THE WEBB ERO PRODUCTION TEAM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December 2022

Mars returns to glory

This month provides a great opportunity to see all five naked-eye planets in the evening sky. But the title for "planet of the month" has to go to **Mars**. The Red Planet reaches opposition and peak visibility December 8, 26 months since its previous opposition. Because Mars lies opposite the Sun in our sky, it remains visible all night. The ruddy planet also comes closest to Earth in December (on the 1st), so it looms largest when viewed through a telescope.

You can find Mars in the northeast as evening twilight fades. It lies among the background stars of Taurus, directly below the Bull's V-shaped head. The planet far outshines the neighboring stars, however, peaking at magnitude –1.9.

For the best views of Mars through a telescope, wait until late evening when it appears higher in the sky. The planet's disk spans 17" in early December. That's plenty big enough to reveal several dark markings during moments of good seeing. The most conspicuous of these is Syrtis Major. The feature resides near the center of Mars' disk in the late evening hours during December's second week.

Jupiter shines at magnitude –2.5 in mid-December, nearly a magnitude brighter than Mars. The giant planet stands high in the northwest as darkness falls and dominates the dim background stars of southwestern Pisces.

Jupiter remains a splendid sight through any telescope. The planet's 42"-diameter disk displays an alternating series of bright zones and darker belts that run parallel to the equator. Smaller atmospheric features pop into view under good seeing conditions. Also keep an eye out for Jupiter's four bright Galilean moons, which stand out clearly when they aren't hidden in front of or behind the planet's disk.

Look lower in the west to spot **Saturn**. The planet lies in eastern Capricornus, whose faint stars are no match for the magnitude 0.7 ringed world.

The best time to turn your telescope toward Saturn is in early evening when it lies farther above the horizon. Any instrument reveals the planet's stunning ring system, which spans 37" and tilts 14° to our line of sight in mid-December. The 8th-magnitude moon Titan also shows up easily. A 4-inch scope brings in a trio of 10th-magnitude moons: Tethys, Dione, and Rhea.

The two inner planets make brief appearances during evening twilight. **Mercury** rises first. The best time to see it comes around its greatest elongation December 21, when it lies 20° east of the Sun and stands 8° high in the west-southwest 45 minutes after sunset. Glowing at magnitude –0.5, it should appear obvious if you have a clear and unobstructed horizon. A telescope reveals Mercury's 7"-diameter disk, which appears slightly more than half-lit at greatest elongation.

Although **Venus** continues to draw slowly away from the Sun in December, it doesn't gain much altitude. On the 31st, it appears 7° high a half-hour after sundown. It likely wouldn't show up at all if it weren't so bright, but its magnitude –3.9 brilliance helps it pierce the bright twilight. A telescope shows a fully lit disk that measures just 10" across.

The starry sky

Brilliant Orion stands out in the northeastern sky after darkness falls in December. But I'd like to focus on two lesser-known though still impressive constellations just above and to the right of the Hunter: Lepus the Hare and Eridanus the River. The north-south border between these two figures lies a few degrees west of Mu (μ) and Epsilon (ε) Leporis.

A few centuries ago, however, another constellation existed between the Hare and the River. A relic of its former presence can be found in the formal name of 4th-magnitude 53 Eridani, a star that lies about halfway between Mu Lep and Gamma (γ) Eri. The International Astronomical Union officially approved the name Sceptrum for this star.

The name came about because it was the brightest star in that former constellation: Sceptrum Brandenburgicum, or the Brandenburg Scepter. A scepter is a staff sovereigns use as a sign of authority.

German astronomer Gottfried Kirch (1639–1710) invented this constellation in 1688. It later appeared in Johann Bode's 1801 star atlas, *Uranographia*. The constellation depicted the scepter of Frederick III (1657–1713), Elector of Brandenburg and Duke of Prussia.

It's hard to make out a scepter's shape in these stars, though a hint of it appears in the form of a line of three faint stars north of Sceptrum that includes 46 and 47 Eri. The upper, decorative top of the specter ran south from 53 and incorporated 54, 58, 59, and 60 Eri.

If you have ever visited Berlin, the name Brandenburg probably rings a bell. One of the most prominent structures in the city is the 18th-century Brandenburg Gate at the western end of Unter den Linden. Historically, the structure marked the start of the road to the town of Brandenburg an der Havel that lies west of Berlin, after which Brandenburg, the German state that surrounds Berlin, is named.

Kirch was an important German astronomer. He made several discoveries, some with his wife and fellow astronomer Maria, including the Wild Duck Cluster (M11) and the globular cluster M5. He became Astronomer Royal at Frederick III's court and was the first director of the original Berlin Observatory.

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

11 P.M. December 1
10 P.M. December 15
9 P.M. December 31

Planets are shown at midmonth

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

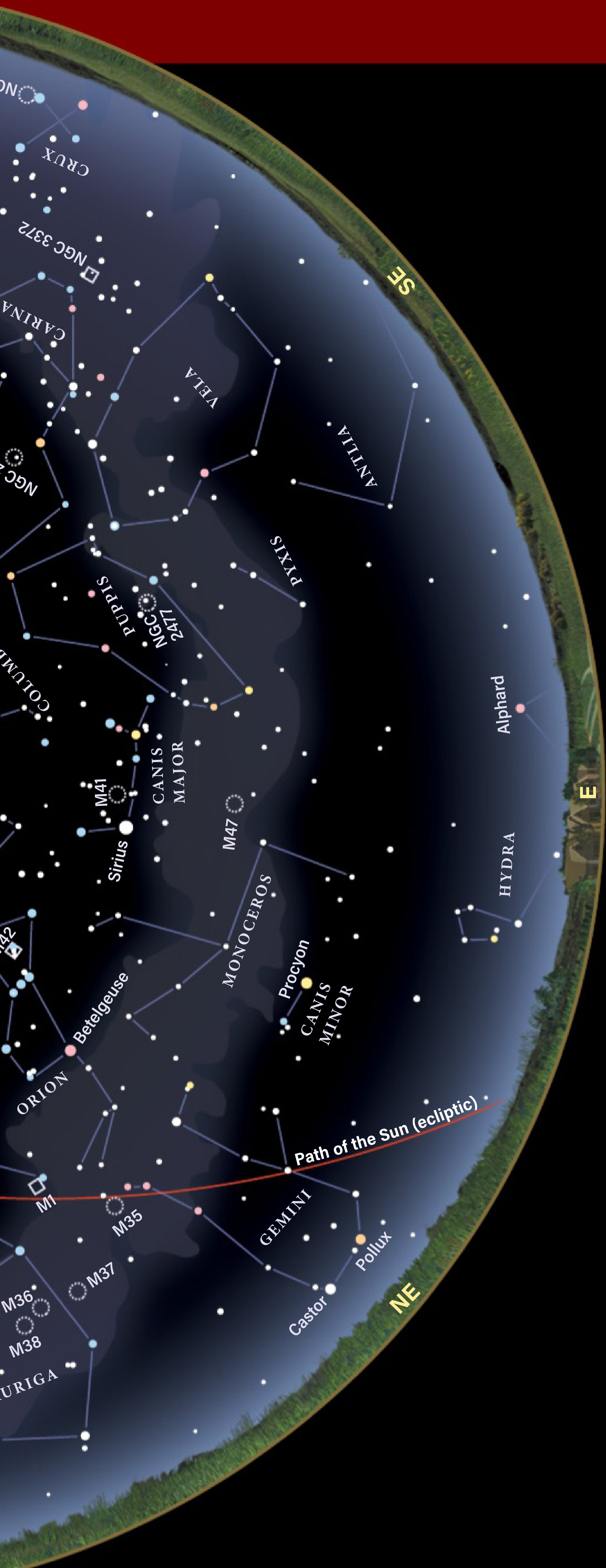
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**



DECEMBER 2022

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1 The Moon passes 1.2° north of asteroid Juno, 0h UT
Mars comes closest to Earth (81.5 million kilometers away), 2hUT
The Moon passes 3° south of Neptune, 13h UT

2 The Moon passes 3° south of Jupiter, 1h UT

4 Neptune is stationary, 10h UT

5 The Moon passes 0.7° north of Uranus, 18h UT

8 The Moon passes 0.5° north of Mars, 4h UT
Full Moon occurs at 4h08m UT
Mars is at opposition, 6h UT

12 The Moon is at apogee (405,869 kilometers from Earth), 0h28m UT

14 Geminid meteor shower peaks

16 Last Quarter Moon occurs at 8h56m UT

21 Mercury is at greatest eastern elongation (20°), 15h UT
Summer solstice occurs at 21h48m UT

22 Mars passes 8° north of Aldebaran, 4h UT

23 New Moon occurs at 10h17m UT

24 The Moon is at perigee (358,270 kilometers from Earth), 8h27m UT
The Moon passes 3° south of Venus, 11h UT
The Moon passes 4° south of Mercury, 19h UT

26 The Moon passes 4° south of Saturn, 16h UT

28 The Moon passes 3° south of Neptune, 20h UT

29 Mercury is stationary, 3h UT
Mercury passes 1.4° north of Venus, 9h UT
The Moon passes 2° south of Jupiter, 11h UT

30 First Quarter Moon occurs at 1h21m UT

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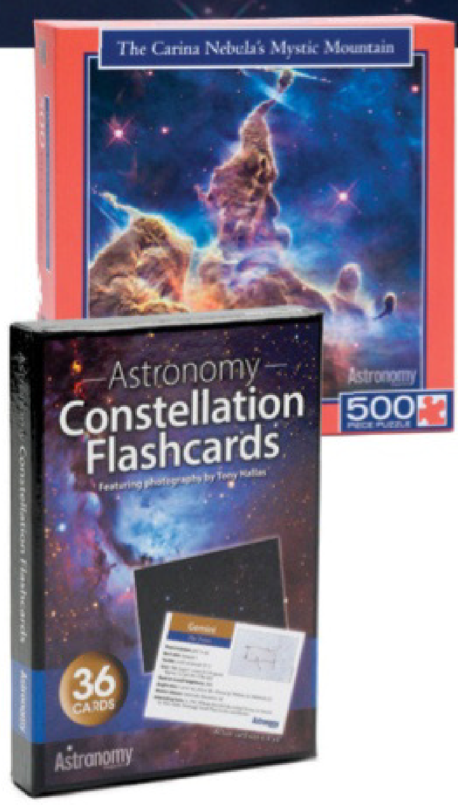

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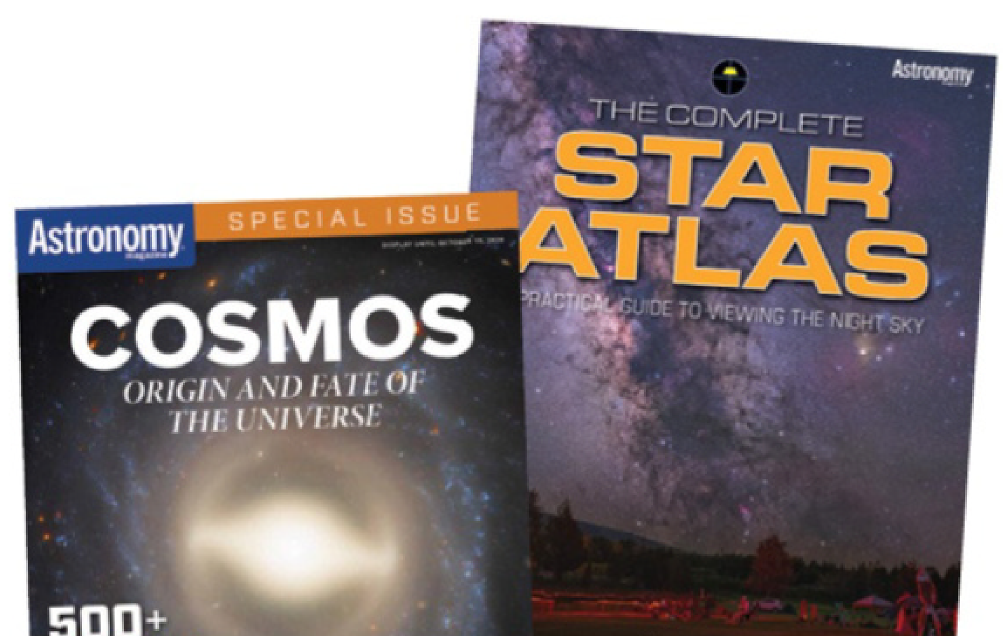

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